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RADIO AMATEUR SATELLITE
CORPORATION

PROCEEDINGS OF THE
AMSAT-NA

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Welcome to Orlando!

It is with great pleasure that I personally welcome you to the 2012 AMSAT Annual Meeting and Space Symposium. This is the 30th Space Symposium, reflecting a long tradition (started in the early 1980's) to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas. AMSAT is proud of the technical content of the papers presented over the years reflecting the inventiveness of our volunteers and the significant contribution of presenters to "advancing the radio art."

The relative importance of the Proceedings in the placement of our technical development work is reflected by the size and scope of this year's edition. Over the past year, AMSAT Engineering has made significant advancements in the design of Fox-1, our first cubesat. AMSAT must comply with the provisions of ITAR (International Traffic in Arms Regulations) that constrains our ability to share technical information of our satellite development efforts UNLESS that information is first placed in the public domain. The only approach that the Directorate of Defense Trade Controls (DDTC) recognizes for placement of information subject to ITAR in the public domain is by physically publishing the material and then making that publication available to the public at large. Consequently, we are placing a significant amount of information regarding our Fox-1 program in this year's Proceedings so that we may publicly discuss our project in greater detail and not be in violation of ITAR. It has always been AMSAT's philosophy that we freely share information about our programs to the extent allowed by US law.

Based in part upon materials presented at last year's Symposium, AMSAT has made significant strides in the areas of education outreach, reflected by the appointment of Mark Hammond, N8MH as AMSAT's VP-Educational Relations. Over the past year, Mark has been developing a team to enhance our capabilities in this area and worked with the ARRL to develop new approaches in support of STEM (Science, Technology, Engineering and Mathematics) that will translate into future opportunities in space. Some of the results of this recent collaboration will be presented at this year's Symposium. Also expect to hear presentations concerning steps being taken by AMSAT to secure future launch opportunities through collaborative relationships with universities. AMSAT will be submitting another ELaNA (Education Launch of Nanosats) proposal to NASA later this Fall in conjunction with Vanderbilt University to fly our second cubesat based upon the "Fox-1" satellite design in 2014.

After forty-three years, we continue to develop remarkable satellites with educational outreach that now serves as the basis for future launch opportunities. Your support will provide a bright future.

73,

Barry A. Baines, WD4ASW
President



Dick Daniels, W4PUJ

One of AMSAT's most important, admired and well loved members, Dick Daniels, W4PUJ passed away on February 14, 2012. He lost his battle with lung cancer, diagnosed only at Christmas time 2011. Dick achieved so much working for AMSAT that it is virtually impossible to enumerate his individual accomplishments. And we cannot overestimate the importance of his sustained support. Dick was many things to us but, among them he was our record keeper, photographic recorder, and the de facto AMSAT historian. So, his loss also represents the loss of many memories of the things we did and the places we've gone as an organization, which simply can't be recorded or kept except in a mind. So, our loss is huge! The records of our earlier spacecraft developments, starting with Australis-OSCAR-5 and continuing to present, amount to over 6,000 individual (non-duplicate) 35 mm slides. These have since been digitized. These were all kept and maintained by him. Many of the photos were his own. Dick was born in Cincinnati, Ohio on May 19, 1932. He received a BBA degree from the University of Cincinnati in Business Management in 1956 and an MBA from the University of Pennsylvania Wharton Graduate School in 1957. He joined NASA HQ in 1961 where he remained until his retirement in 1994. Dick became a licensed radio amateur in 1959. He was involved with the formation of AMSAT in 1970 and served on the AMSAT Board of Directors from 1992 to 2003.

Dick was one of the initial AMSAT members and was Life Member 11... His first major contribution to amateur radio was his work to obtain permission from the NASA Administrator (then James Fletcher) and the NOAA Administrator (then Jack Townsend) for the launch of Australis-OSCAR-5. It was Dick who pushed our AMSAT letter proposal for the launch of AO-5 through the NASA and NOAA systems. Dick was also heavily involved in our efforts to license AO5 with the FCC. That was a much bigger deal back in 1970 than it is today. Few will appreciate the resistance we had within the system from the TIROS project office at NASA/GSFC and what had to be done to overcome it. Few will also remember the support we had from places we didn't expect, but, with Dick's help and all of us pushing – we were in “business” – the “business” of building satellites for free.

Dick became AMSAT-NA's primary mechanical designer and technician, having helped design and then assemble just about every spacecraft structure we launched starting with AMSAT-OSCAR-6. At the beginning of the Phase-3 era it became clear that AMSAT needed to go into the propulsion business if we were going to get to higher orbits and Dick took on the role of chief propulsion expert, in addition to his mechanical technician duties. Dick and I installed the Thiokol solid propellant kick motor into the ill-fated Phase-3A satellite once it

arrived in French Guiana and it was Dick, working with MBB who loaded the bi-propellant fuels (UDMH or AZ-50 and N2O4) on-board AO-10, AO-13 and AO-40 (all very dangerous compounds). Even though the rocket motor each time was pure German technology, Dick was the one we all trusted to handle the exacting task of propellant loading. He also developed, assembled and tested all of the PFAs (propellant flow assembly) units that controlled the fuel flow and pressurization of each of the propulsion systems. He also contributed significantly to their design details. The utilization of real, high performance propulsion systems on small satellites is still something no other small satellite organization other than AMSAT has successfully achieved.

Few have even attempted to follow in our footsteps. We've had our difficulties with rocket motors (and what organization that has tried to use them has not?) but, at least AO-13 was perfect. No professional organization has ever done much better than the performance of that propulsion system. And, in large measure, the success of that system can be credited to Dick Daniels. The other P3 satellites, at least had partially successful motor firings, except for Phase-3A which was lost due to a launch vehicle failure, hence we never had a chance to fire our solid rocket motor. Dick constructed the AO-6 2M/10M transponder, designed by Perry Klein (W3PK) and Karl Meinzer (DJ4ZC). He also constructed the follow-on unit flown on AO-7. He assembled major portions of the receiver units forming both the command system and packet communications system developed by Tom Clark (W3IWI) for the four Microsat spacecraft launched in 1990. Dick assembled so much hardware that if you were to look at each individual sub-assembly that he built or worked on – as they exist in our master photo set – and you viewed each slide for 10 seconds, it would take over an hour to view all of them! That is a lot of space flight hardware.

Dick loved space flight, he loved the challenge represented by the amateur satellite program and he loved working with our many friends around the world. Together we accomplished something that will take years before others reproduce. More importantly, with Dick's huge support we actually created a new industry. Few lives can claim to have done that. The Small Satellite Industry is very alive and well and, as a sector of all space commerce it is now the fastest growing area. If Dick had not made his contributions, AMSAT would have had a very different history but, because of him and others who worked so hard to get things started, AMSAT is at the root of all of today's small satellite technology. This is a fact, not wishful thinking.

Dick also loved nature and the outdoors. We spent many happy times hiking in the mountains of Virginia, using the "famous" Daniels "cabin" as a base camp. We had great times chasing butterflies and watching sea turtles in French Guiana. Dick has a wonderful family and even though AMSAT took a significant fraction of his free time his daughter Kathy and his son Robert are proud of his accomplishments. Like all AMSAT "widows" Jackie supported Dick's "hobby" with enthusiasm and never complained about her time alone when Dick was integrating AMSAT spacecraft on the night shift (sometimes at home and sometimes with me at the AMSAT lab). His family will miss him terribly as he was not just an average father and husband.

Dick spent a lot of time working on the gantry level of many launch vehicles, installing AMSAT spacecraft on Delta and Ariane launchers and, as a NASA-HQ employee, he built more space flight hardware in his basement than anyone working for NASA in Washington, D.C. ever even saw in a lifetime. He loved life and he made his count. And he made a huge difference to the outcome of our hobby and our belief in what an individual can do in space.

So, we've lost someone that meant a lot to us all and someone who will be impossible to replace. History may repeat itself but, it will be a long time before someone like Dick Daniels, with his unique set of skills comes our way again. So, W4PUJ is SK. This is a sad day for amateur radio and to the small satellite space community and even more for those of us who loved him.

Dick, you made a difference and it will be a long time still before others reach where you have been. What you did wasn't just worthwhile – IT WAS FANTASTIC! I'll never forget our time working together! It was an amazing hobby, really! An amazing LIFE!

Jan A. King W3GEY/VK4GEY



Dee Interdonato, NB2F

Dee Interdonato, NB2F, passed away on April 8, 2012. Dee was one of the editors of the AMSAT News Service and an AMSAT New Jersey Area Coordinator. He was the main point of contact for many amateurs as he covered most of the New Jersey hamfests on behalf of AMSAT. Dee was one of the mainstay volunteers for AMSAT at the Dayton Hamvention for years. He also gave satellite presentations for the clubs in New Jersey. Dee helped where ever he could, often behind the scenes. He worked on QSL duties for SAREX, ARISS, and ARISSat-1 missions so many of you have likely received a card from him.

Dee was a well known and respected mentor for amateur satellite operators, helping them understand the technical details and make successful radio contacts via satellites. Dee's other amateur radio activities in Northern New Jersey included the Bergen Amateur Radio Association, Bergen County CERT, AMSAT, and he was the treasurer of the Bergen County FM Association. Dee, and his wife Ginny, N2EYN always participated in the Dayton Hamvention and AMSAT Symposiums.

Dee was the principal trumpet player for the Rutherford Community Band and a member of the Waldwick and Westwood Community Bands. He was also an avid hunter and a member of the Association of New Jersey Rifle and Pistol Clubs. Before retiring he was the supervisor of the Radio Shop of the Port Authority of NY/NJ.



John Beanland, G3BVU

John Beanland, G3BVU, passed away after a long illness on September 21, 2012 at the age of 85. John was an avid AMSAT member and helped man the AMSAT booth at the Boxboro Hamfest over the years. His friends remember John to be outgoing and enthusiastic about amateur radio in space. AMSAT President Barry Baines, WD4ASW noted, "AMSAT has lost a good friend and enthusiastic member."

Charles "John" Beanland was born in Witney, England. John enlisted in the UK Navy during WWII. He was first licensed as G3BVU in 1947. He worked for Post Office in Engineering and English Electrical Valve where he worked on Guided Weapons. He later joined Texas Instruments and finally Microwave Associates, UK where he developed VHF solid state power amplifiers, all while attending and receiving BS degrees in Electrical Engineering, Radio and Telecommunications.

Microwave Associates transferred him from the UK to Burlington, MA in 1963. In 1966 he joined the MITRE Corporation in Bedford, MA as a Member of the Technical Staff working on microwave systems and Over The Horizon Radar HF direction finding systems until his retirement in 1993. During that time he received his Masters Degree in Electrical Engineering from Northeastern University. In 1972 he acquired Spectrum International, specializing in antennas, filters, VHF transverters and satellite tracking systems which he operated until his passing. He later received his US call sign, AA1YE and taught Amateur Radio licensing courses and HF radio propagation at local radio clubs.

John was married to Dorothy Beanland for 57 years. They have three children and three grandchildren.

An Overview of the ARISSat-1 Mission
Barry A. Baines, WD4ASW
President, AMSAT

Introduction

This paper provides a review of the ARISSat-1 mission and outlines the accomplishments that were achieved both in terms of technical objectives as well as how the satellite impacted users on the ground. While student educational outreach is a primary consideration, there are also other educational impacts that were achieved in terms of 'life long learning' as the interest in the satellite during its deployment was extensive around the world. Where AMSAT is able to utilize measures of educational and other interest, I have incorporated those statistics in this review. Where there is anecdotal evidence of interest, those are used as well.

Background

ARISSat-1/RadioSkaf-V is the prototype of a new class of amateur radio satellites that is designed to provide a platform for student education activities in space. The spacecraft was designed and built by AMSAT (Radio Amateur Satellite Corp.) volunteers. AMSAT, based in Silver Spring, MD is a not-for-profit scientific and education organization. The ARISSat-1 program was endorsed by ARISS-I (Amateur Radio on the International Space Station-International), a consortium of amateur radio organizations which serves as a governing body for amateur radio activities on the ISS.

Following the SuitSat-1 mission, AMSAT and RSC-Energia agreed in Fall 2006 to have a follow-on mission with a vastly enhanced capability. RSC-Energia agreed to support the mission by providing cargo space on a Progress Cargo Vessel as well as handling the deployment of SuitSat-2 during a Russian EVA. The flight of SuitSat-2 (later changed to ARISSat-1) was considered to be a Russian project with the assignment of a Russian amateur radio satellite service call sign (RS01S) to the spacecraft that was broadcast as part of its routine transmissions to the ground identifying the source of the transmissions. A student payload developed by Kursk State Technical University to measure the vacuum of space was to be added to the spacecraft once it reached Moscow.

However, due to an increase in crew size on the ISS in 2009, the surplus suit was discarded due to lack of storage space and the design was altered to incorporate a mechanical structure designed around the SuitSat-2 components, including the SMEX solar panels that had been provided by NASA GSFC to the project. The revised program was renamed ARISSat-1 to reflect the new design. AMSAT was able to design and build the new mechanical structure and rework the relative placement of subassemblies within the new space frame (which required new cabling) in less than a year.

Because the design of ARISSat-1 offers the potential for deploying multiple student experiments from the ISS, the ISS National Lab Education Manager was very interested in having the prototype demonstrate its capabilities and NASA took significant interest in

the ARISSat-1 mission. Under a protocol signed by AMSAT, RSC-Energia and NASA in 2010, NASA formally agreed to provide critical support to the project, including leading the Payload Safety Review Panel (PSRP) process, conducting a re-contact analysis for the deployment of the satellite, and handling export control certification and export control documentation prior to shipment of the spacecraft to RSC-Energia. NASA also coordinated the logistics of shipping the satellite and back-up unit from JSC-Houston to Moscow.

Following vibration and thermal tests, in October 2010 the flight unit and backup flight unit were shipped to Johnson Space Center, Houston for furtherance to RSC-Energia. The spacecraft and flight backup arrived in Moscow in December 2010, with charging/installation of an Orlan spacesuit battery provided by RSC-Energia, the addition of the Kursk Experiment, and subsequent checkout of the primary spacecraft conducted by RSC-Energia. Once preparations and tests were completed in Moscow, the Orlan battery was removed from the spacecraft, the spacecraft and battery were prepped for stowage and subsequently shipped to Baikonur for placement on Progress-41P in January 2011. ARISSat-1 was on board the International Space Station from mid-January 2011 until deployment on 3 AUG 11 during the second Russian EVA of 2011.

The spacecraft operated successfully until 4 JAN 12 when it de-orbited. Details of spacecraft performance are discussed later in this paper.

Spacecraft Capabilities/Purpose

The ARISSat class of spacecraft is designed with education outreach as its primary purpose. The ARISSat spacecraft design incorporates a number of education-based features:

- **Student Experiments:** The spacecraft is equipped with three experiment ports that allows data from each experiment to be incorporated into the spacecraft's telemetry stream to be received by ground stations. AMSAT developed telemetry software for both the PC and Mac Operating Systems that would allow ground stations to analyze spacecraft parameters, view the payload data as well as automatically have the received payload and spacecraft data forwarded to a central server by the receiving station via the internet for storage and subsequent availability. ARISSat-1 had one experiment installed, provided by Kursk State Technical University (Russia) to measure the vacuum of space.
- **SSTV downlink of images** taken by four cameras onboard the spacecraft and transmitted in a SSTV format that could be demodulated by a computer program on the ground. Users could then elect to forward their received images to the ARISS SSTV Gallery: <http://www.amsat.org/amsat/ariss/SSTV/>
- **Student voice greetings** transmitted by the spacecraft's two meter FM downlink. A total of 24 messages in 15 different languages were recorded by students around the world prior to launch and subsequently transmitted by the spacecraft once deployed. Each greeting also incorporates a 'secret word' meant to

encourage students to receive and hear the downlink in order to determine the secret word as part of a contest. A properly tuned FM receiver capable of reception of 145.95 MHz with hand-held external antenna (such as an Arrow or Elk antenna) is more than sufficient to receive signals.

- Telemetry downlink of both the spacecraft's condition and the student experiment(s) using a new protocol (BPSK-1000). This telemetry process requires a SSB receiver and software developed by AMSAT. A backup telemetry channel is also available using an older and less capable protocol (BPSK-400) in the event there are technical issues with the new protocol.
- Voice telemetry transmitted on the FM downlink channel (the same one used to transmit student greetings) provides a means for students to directly collect the satellite's critical parameters without the use of a PC by listening for 'spoken' data on a VHF receiver as the satellite passes within radio range of the ground receiver.
- Orbital Analysis. The "Chicken Little Contest" was held for students and individuals to predict when the satellite would de-orbit. As the satellite was deployed from the ISS, it would be a matter of time when the satellite would re-enter the earth's atmosphere and be destroyed.

Along with serving as a platform for education outreach, ARISSat-1/RadioSkaf-V also served other purposes as well:

- Communications technology platform: ARISSat-1 serves as a testbed for several new technologies to demonstrate the viability of designs for future amateur radio spacecraft. The Software Defined Transponder (SDX) allowed the spacecraft to transmit on four different carrier frequencies using different operating modes all at the same time. To our knowledge, ARISSat-1 is the first amateur radio spacecraft to have both its receiver and transmitter ("transponder") operate as software defined units.
- Power Management technology platform: The Maximum Power Point Trackers (MPPTs) are dc-to-dc power converters designed to draw the maximum amount of power from each solar panel with no command from the ground. The satellite has six panels (one on each side), each capable of producing up to 50 volts open-circuit and 19 watts of power (depending upon sun angle). Each panel has a MPPT attached to it. A key benefit of using MPPTs is that it allows the operating system to be designed with very little command and control from ground stations. The spacecraft was designed to manage the power on its own, which is unique for amateur radio satellites. The success of this approach will be reflected in future AMSAT satellites.
- Demonstration of a new data communications protocol: The newly developed BPSK-1000 protocol by Phil Karn, KA9Q is designed to allow a significant

amount of data (both satellite telemetry and student experiment data) to be properly received on the ground despite signal nulls and fading, significantly improving data reception over earlier protocols.

- **Amateur Radio Transponder.** The spacecraft incorporates a 70 CM uplink, two meter downlink linear transponder with a 16 KHz wide bandwidth. Licensed amateur radio operators around the world can use this transponder to communicate with other amateurs as long as both parties are under the “footprint” of the satellite. The width of the transponder (16 KHz) allows about four independent sets of conversations to take place at one time without interference from the other sets of transmissions.
- **CW (“Morse Code”) Reception:** ARISSat-1 also transmitted in “Morse code” the amateur radio call signs of key individuals who have made significant contributions to amateur radio in space since the launch of OSCAR-1 in December 1961. Individuals were encouraged to ‘decode’ at least six of the call signs transmitted and submit their entries for recognition of their accomplishment. This contest not only recognized the achievements of those whose call signs were part of the contest, but a fun way to encourage individuals to ‘try CW’ as a means of enhancing their radio receiving skills.

The CW ‘beacon’ also serves as a “relative tuning indicator” for tuning the ground station receiver to the frequency being used for receiving telemetry. As there are two modes of telemetry (the new BPSK-1000 and the older BPSK-400 used on earlier AMSAT spacecraft) on two different frequencies with only one being active at any one time, the frequency of the active CW beacon reflects which telemetry mode and frequency is being used. When the receiver is properly tuned for proper CW reception, it is also properly tuned for receiving the telemetry downlink given the relationship between the CW and associated BPSK downlink frequencies.

- **50th Anniversary Commemoration of the Flight of Yuri Gagarin:** RSC- Energia renamed the satellite from RadioSkaf-V to Kedr in recognition of the call sign for Yuri Gagarin’s epic flight in April 1961. Following the arrival of ARISSat-1/Kedr to the ISS in January 2011, RSC-Energia decided to not have the spacecraft deploy during a planned EVA in February 2011. As the 50th anniversary of Yuri Gagarin’s flight was to be celebrated in April, the satellite was retained on board the ISS with the expectation that the satellite’s uplink receiver and downlink transmitter (in low power) would be connected to external antennas on the ISS so that ground stations could use the satellite (on the satellite’s battery power) as part of the commemoration.

Unfortunately, the satellite was not heard on the ground during this test. Based on the available technical information from RSC Energia, we believe the antenna cable was not connected to the correct port on the ISS patch panel. Nonetheless,

the fact that RSC-Energia decided to postpone deployment and wanted to use the satellite as part of the 50th anniversary Gagarin commemoration (a major event in Russia) speaks well of the significant recognition given to ARISSat-1/Kedr.

Creating Ground-Based Support for the ARISSat-1 Mission

While AMSAT was primarily focused on completing the ARISSat-1 spacecraft, there were also parallel efforts to create needed support mechanisms for the mission as well. These included:

- Creation of a website dedicated solely to the ARISSat-1 mission. The website www.arissat1.org was developed to serve as the primary source of information on the mission and spacecraft particulars. News items about the mission, display of the latest received telemetry values that had been forwarded to the ARISSat-1 data collection site, links to download ground station software, FAQs about the hardware onboard, explanation of the various contests that were held, and other materials were posted.

While AMSAT intended to post educational content that could be adapted for classroom use to encourage teachers and students to use the ARISSat-1 satellite as an educational tool, AMSAT was unable to find volunteers with the necessary qualifications needed to post such materials prior to mission completion. This is an area that is now being addressed by AMSAT with the appointment of a VP-Educational Relations in December 2011 (Mark Hammond, N8MH) as AMSAT establishes a team that is now focused on education issues. In addition, there are now conversations currently taking place between AMSAT, ARRL, and NASA JSC-Education by the "Education Working Group" to define the vision and scope of how these three groups can work together in areas of mutual interest in educational outreach utilizing amateur radio satellite assets. AMSAT's expectation is that education materials that are developed would be appropriate for future flight opportunities.

- Creation of software to receive satellite telemetry and payload data. Douglas Quagliana, KA2UPW/5 developed a PC-Based application called "Windows ARISSatTLM" while Gilbert Mackall, N3RZN developed "Mac ARISSatTLM" for Apple computers running Mac OS 10.x. Both applications utilize the newly developed BPSK-1000 protocol developed by Phil Karn, KA9Q to transmit data to the ground as well as display the CW ("morse code") transmissions from the spacecraft. Both applications were made available on the ARISSat-1 website by the time the satellite was deployed along with a "ARISSatTLM Software Quick Start Guide".
- Development of a server site to receive satellite telemetry and payload data. Ground stations receiving the RAW telemetry and KURSK frames from ARISSat-1 as it passes overhead have the option of forwarding the collected data to a

central server site (arissattlm.org). In addition, the central server provides to the arissat1.org website the latest telemetry values received at the server site from the remote ground station that received the most recent data values. This data is displayed in the 'Telemetry' tab. Further, users with mobile devices, such as an iPhone or Android phone, could connect directly to the arissattlm.org website to have the latest telemetry values displayed on their mobile device. See: www.arissattlm.org/mobile.

The advantage of the 'mobile' display of telemetry is that it allows individuals to monitor the latest reported condition of the satellite when that person is unable to monitor the satellite as it passes overhead. Students, for example, without access to amateur radio equipment can still review telemetry data from the spacecraft.

- Recruiting volunteers to handle the variety of reception certificates requests. In order to encourage individuals on the ground to listen for the ARISSat-1 downlinks and take full advantage of the satellite's capabilities, a number of programs were established to foster interest in the satellite. The certificates are awarded based upon ground station/individual self-reporting. These opportunities are listed on the ARISSat-1 website. See: www.arissat1.org/v3/index.php?option=com_content&view=category&layout=blog&id=52&Itemid=114

Each certificate is described below along with the number of certificates requested:

- Voice Telemetry Reception Certificate: Given to individuals who provide documentation of the voice telemetry data received from the satellite on the FM downlink (145.950 MHz). A total of 232 US and Canadian requests were received plus 125 requests from other countries.
- Greeting/Secret Word Contest: Given to individuals who e-mail the secret password heard during one (or more) of the 24 pre-recorded greetings in 15 languages transmitted on the FM downlink (145.950 MHz). A total of 334 US and Canadian certificates were received plus 423 from other countries.
- "Chicken Little" Contest: Subsequent to deployment on 3 AUG 11, AMSAT announced a contest whereby individuals had until 15 OCT 11 to predict the date and time that the satellite would de-orbit. Several categories of entrants were created, including middle school and high school students. Following de-orbit of the satellite, those individuals in each category whose estimates were closest to the actual de-orbit would be recognized. The breakdown of submissions:

Adults: 53 submissions from 13 countries and 6 continents
K-8: 3 classes/clubs, USA and Germany
19 individuals. mostly from the same US school
High School: 2 classes/clubs, UK and Hungary
1 individual, UK

The winning entries:

K-8: Cora Haefner, KK4ECV, Fort A.P.Hill, VA

High School: Cameron, Lancashire, UK

Adult: Thomas Frey, HB9KSA Birr, Switzerland

Cora, KK4ECV and Thomas, HB9SKA were both within 15 hours of the Space Track reports. All three winners have received an appropriate Chicken Little Certificate and the congratulations of the ARISSat-1/KEDR Team.

- CW Contest: Individuals were encouraged to copy as many of the amateur radio call signs transmitted on the satellite's CW beacon as possible. A minimum of six properly identified call signs was required. Individuals who successfully copied at least six of the call signs could receive a recognition certificate. A total of 19 entries were received.
- SSTV Image Reception Certificate: Given to individuals who provided a description of the SSTV image (Robot-36 format) they received from the satellite on the FM downlink (145.950 MHz). A decoding device (PC with appropriate software connected to the audio output of an FM receiver or a special device designed to display a SSTV image connected to the audio output of a FM receiver) was required to see the image. SSTV software was available on the www.arissat1.org website. A total of 138 US and Canadian certificate requests were received plus 198 from other countries.

The total of all certificates requests as of 7 JAN 12 (shortly after de-orbit) was 1,450. Some of these requests could be multiple certificate requests from the same individual. However, the number of requests does suggest significant interest in the ARISSat-1 satellite by amateur radio operators and others around the world. Given that for most of the satellite's operation was only in daylight (due to the failure of the Orlan battery), one can only surmise how much additional interest there may have been if the satellite was functional during eclipse. Unfortunately, we do not know how many of these student requests were from students.

Likewise, another relative measure of ground-based interest in the satellite is the number of SSTV images that were downloaded and subsequently forwarded to the ARISS SSTV Gallery (www.amsat.org/amsat/ariss/SSTV). The first SSTV image uploaded to the Gallery took place within a few hours after deployment on 3 AUG 11 at

2007 CDT from a station in Asia. Among the early images received is one of the helmet of the cosmonaut that deployed the spacecraft. The last image uploaded was acquired on 3 JAN 12 at 2125 CST. This was about 12 hours prior to de-orbit of the spacecraft. A total of 3,592 SSTV images were submitted to the Gallery from all over the world. Given that the satellite was in operation for 153 days, an average of 23.5 images were uploaded each day to the Gallery. Clearly, users who successfully received these images were excited to receive these images and wanted to share their results.

NASA Dissemination of ARISSat-1 News

The deployment of ARISSat-1 during the Russian EVA-29 on 3 AUG 11 was carried live by NASA TV. It is unknown how many viewers watched the deployment, but presumably it was in the thousands. The NASA commentator did an outstanding job describing ARISSat-1 and its purpose. When the deployment was halted due to concerns about the 70CM antenna, the commentator did an excellent job of explaining the concerns and the rationale for delaying deployment until later in the EVA. On the bottom of screen the AMSAT website address was also displayed on occasion.

Subsequent to deployment, NASA posted information on their website about the satellite: <http://www.nasa.gov/audience/foreducators/hammin-it-up.html>

A "NASA Education Express Message" was released on 4 AUG 11 that included an article on ARISSat-1's deployment. According to NASA, this message was sent to 18,516 Express Subscribers and 1,285,892 NASA Twitter account subscribers. The express message of 4 AUG 11 is currently available in the NASA archive: http://blogs.nasa.gov/cm/blog/educationexpress/posts/post_1312477915862.html

In addition, there was some media reaction to the ARISSat-1 deployment. For example: <http://www.wbir.com/news/article/178784/2/STEM-education-reaches-new-heights> This news video featured ARISSat-1 Project Manager Gould Smith, WA4SXM as WBIR-TV in Knoxville, TN is located where Gould lives.

AMSAT Media Relations

AMSAT's volunteers worked to provide information about ARISSat-1 to both the amateur radio community and the general public, including educators and students. AMSAT's media focus has traditionally been aimed towards the amateur radio community through several outlets:

- The arissat1.org web site was specifically set up for this purpose and provided multimedia content of the launch, deployment, operating information, photos of the satellite under construction and technical presentations.
- AMSAT News Service (ANS) is the primary mechanism for distribution of timely information. The Weekly ANS Bulletin is released weekly (generally on Saturdays) and distributed throughout the world via various mechanisms, including e-mail distribution, packet radio (particularly overseas), and posting on various amateur radio websites (including www.amsat.org) around the world. Reports on the development of ARISSat-1 were routinely provided and as

deployment and subsequent operational matters were made know, special bulletins or inclusion in normally scheduled distribution were used to provide this information.

ANS bulletins are also read on various AMSAT nets, such as the Sunday 20 Meter Net held at 1700 UTC on 14.282 MHz.

- AMSAT Journal is AMSAT's bi-monthly magazine distributed to the AMSAT's membership. Technical details on ARISSat-1 were published as the satellite's expected deployment date approached.
- AMSAT-BB provided by AMSAT is a public mailing list subscribed by both AMSAT and non-AMSAT members focusing on general information and discussion pertaining to amateur radio satellites and space technology. Questions/comments about ARISSat-1 are often raised here and members of the engineering team or the AMSAT leadership have typically responded to these queries.
- Proceedings of the AMSAT Space Symposium is published annually in conjunction with AMSAT's annual Space Symposium. Starting in 2007, papers on the development of SuitSat-2 and later ARISSat-1 were published in the Proceedings as well as presented at the conference. On average, about 100 attendees register for each symposium, which take place in October or November of each year at various locations around North America.
- Articles in other radio publications. Dave Jordan, AA4KN wrote an overview of the ARISSat-1 project ("Get Ready for ARISSat-1") that was published in the February 2011 issue of QST, the monthly journal of the American Radio Relay League (ARRL) with a membership of over 156,000. The magazine cover featured a photograph of ARISSat-1 as it was being prepared for vibration testing in Orlando, FL. With the permission of the ARRL, Dave's article was subsequently made available on the www.arissat1.org website.

Keith Baker, KB1SF/VA3KSF highlighted ARISSat-1 in several of his "SkySurfing: Radio From the Outer Reaches" quarterly columns that are published in Monitoring Times. His February 2012 column, for example, provided an update on the status of the satellite, the degree of interest generated in the various 'contests' and the interest in telemetry forwarding accomplished to date. Monitoring Times, published monthly by Grove Enterprises, is aimed primarily to short wave listeners (SWLs), scanner enthusiasts, and amateur radio operators.

Terry Douds, N8KI writes an 'Amateur Satellites' column in World Radio, published by CQ Communications as an electronic magazine aimed primarily at amateur radio operators. Terry has included updates on ARISSat-1 in his column.

- Tony Monteiro, AA2TX, AMSAT's Vice President of Engineering wrote an article about the Software Defined Transponder (SDX) for the special Technology issue of CQ magazine published in November 2011.
- American Radio Relay League (ARRL). The ARRL releases bulletins that are sent via e-mail and radio means. A special bulletin was released on 4 AUG 11 announcing the deployment of ARISSat-1. In addition, The "ARRL Letter" is sent via e-mail to subscribers and the 4 AUG 11 issue also included information about ARISSat-1's deployment. The 4 JAN 12 issue of the "ARRL Letter" noted the loss of the satellite due to its de-orbit.

Non-Amateur Radio Publications. AMSAT volunteers, led by Dave Jordan, AA4KN and Keith Baker, KB1SF compiled a list of over 100 key news organizations (newspaper, TV, radio), NASA education personnel, and foreign AMSAT organizations to receive AMSAT News Releases on ARISSat-1.

Several AMSAT New Releases were subsequently sent to these recipients, including ones dated 3 AUG 11 ("ARISSat-1/KEDR satellite begins its mission after a successful deployment from the International Space Station"), 7 OCT 11 ("ARISSat-1/Kedr team announces CW Contest"), and 5 JAN 12 ("ARISSAT-1/KEDR AMATEUR RADIO SATELLITE DEORBITS"). As AMSAT doesn't have the means to monitor media activity, we are not in position to know how many outlets used our materials. However, Space Daily did note the de-orbit of ARISSat-1 in an issue following our media release using our write up. See: http://www.spacedaily.com/reports/ARISSat_1_KEDR_Amateur_Radio_Satellite_Deorbits_999.html

- You Tube Video on ARISSat-1. Many video postings are available online pertaining to ARISSat-1. At the 2011 AMSAT Space Symposium in San Jose, CA held 4-6 NOV 11, ARRL's Bob Allison, WB1GCM interviewed AMSAT's ARISSAT-1 Project Manager Gould Smith, WA4SXM about the spacecraft capabilities and the mission's focus on educational outreach. See: http://www.youtube.com/watch?v=NJ_-2wNmFqc&feature=youtu.be

Tucson Amateur Packet Radio President Steve Bible, N7HPR was interviewed on a live weekly internet-based TV show called "Ham Nation" on Tuesday, 6 SEP 11 (Episode 16). The show's format is similar to 'late night TV'. Steve is a member of the ARISSat-1 engineering team. His comments/observations on ARISSat-1 and ARISS may be found here: <http://www.youtube.com/watch?v=mjY7r2Gmc1E&feature=related>

The complete "Ham Nation" broadcast of Episode 16 may be found here: <http://www.youtube.com/watch?v=Gp6BT1QWMGg>

A query of You Tube using "ARISSat-1" as the search item returned over 320 You Tube entries. Many of these video postings relate to reception of ARISSat-1

signals as well as information about how to listen for the satellite. For example, there is a video that explains telemetry decoding reception. Many of these videos were posted by non-US citizens. In addition there are two videos on vimeo.com, including one recorded at 1500 local on 2 JAN 12 (two days prior to de-orbit) by VE7DAO in Canada where the FM downlink is clearly heard. See: <http://vimeo.com/34687835>

The overall degree of interest in the satellite on You Tube and Vimeo is compelling, reflecting a real interest in the satellite worldwide. After all, it takes planning and preparation for someone to take the time to record and post a video, meaning that the individual doing so is excited about the subject matter (in this case, their experience with ARISSat-1).

One item not specifically evaluated is the number of "hits" that the ARISSat-1 videos have generated online. Assuming for a moment that each video typically is viewed 100 times and given that there are 322 videos posted, this might suggest at least 32,200 "hits". There are also videos such as the "Ham Nation" interview of Steve Bible, N7HPR that are significantly higher in viewership. That video has been viewed over 1,060 times. Again, the outreach of ARISSat-1 through social media is significant and I have likely understated the actual impact.

- A recent search of the term "ARISSat" on Google produced over 625,000 hits showing substantial world wide interest. Of course a few of those are from our own AMSAT site.
- On-Line Blog. Steve Bible, N7HPR has written a series of 'blog posts' in "EE Times" (produced by UBM Electronics) that was started shortly before deployment. The series of blogs is titled "Chips in Space - Building an Amateur Radio Satellite. See:

9/24/11: <http://www.eetimes.com/electronics-blogs/chips-in-space/4228027/Chips-in-Space--Lessons-learned--Part-2->

9/17/11: <http://www.eetimes.com/electronics-blogs/other/4227392/Chips-in-Space--Lessons-learned--Part-1->

9/10/11: <http://www.eetimes.com/electronics-blogs/chips-in-space/4226864/Chips-in-Space--Just-the-FAQs-Ma-am>

9/03/11: <http://www.eetimes.com/electronics-blogs/chips-in-space/4219588/Chips-in-Space--Design-challenges--intrigue-and-solutions>

8/27/11: <http://www.eetimes.com/electronics-blogs/chips-in-space/4219352/Chips-in-Space--Let-s-look-inside-ARISSat-1--Part-3->

8/21/11: <http://www.eetimes.com/electronics-blogs/chips-in-space/4219183/Chips-in-Space--Let-s-look-inside-ARISSat-1--part-2->

8/13/11: <http://www.eetimes.com/electronics-blogs/chips-in-space/4218756/Chips-in-Space--Let-s-look-inside-ARISSat-1--part-1->

8/07/11: <http://www.eetimes.com/electronics-blogs/chips-in->

[space/4218536/Chips-in-Space--SuitSat-2-becomes-ARISSat-1--When-we-lost-our-suit---not-really-](http://www.eetimes.com/electronics-blogs/chips-in-space/4218536/Chips-in-Space--SuitSat-2-becomes-ARISSat-1--When-we-lost-our-suit---not-really-)

8/04/11: <http://www.eetimes.com/electronics-blogs/chips-in-space/4218501/Chips-in-Space--ARISSat-1-deployment-update>

7/29/11: <http://www.eetimes.com/electronics-blogs/pop-blog/4218353/The-importance---challenges-of-collaboration>

These articles generated a significant amount of interest with the "EE Times" readership from both amateurs and non-amateurs alike. The issues of project management as well as the 'lessons learned' are areas that created much feedback and comments.

Information about UBM Electronics and "EE Times" may be found here: <http://ubmelectronics.com/mediakit/>

Technical Results of the ARISSat-1 Mission

ARISSat-1 served as a technical testbed for new technologies, including the Software Defined Transponder (SDX), development of a new Forward Error Correcting protocol (BPSK-1000), and use of Maximum Power Point Tracker (MPPT) to improve the efficiency of power generation from solar panels. All three of these technologies worked exceedingly well. The SDX in particular was stellar, providing simultaneous transmissions on multiple two-meter downlink frequencies, each using a different transmission mode:

- FM Downlink at 145.950 MHz providing 24 student greetings in 15 languages, voice telemetry and SSTV images
- CW Beacon at 145.920 MHz providing telemetry in CW, amateur radio call signs of instrumental amateur satellite program volunteers (the 'cw contest'), and satellite id (RS01S)
- Digital BPSK-1000 telemetry beacon at 145.919 MHz providing spacecraft telemetry and Kursk experiment data
- 16 KHz wide amateur downlink (145.922-145.938 MHz) with the uplink using 435.758-435.742 MHz in a linear, inverting transponder mode

While the SDX worked flawlessly, the 70CM-2 Meter transponder suffered from a damaged 70 CM receive antenna that is not used for student-based education outreach but only for amateur radio transponder (two-way) communication via the satellite. During the deployment on 3 AUG 11, it was discovered that the 70 CM 'whip' was missing and not connected to the base of the antenna. When or how it was damaged is unknown, though it is clear that the cosmonauts deploying the satellite were unaware that there was supposed to be a second (70 CM) antenna installed on the spacecraft. This suggests that the original configuration instructions for deployment may not have been followed because of the use of the satellite inside the ISS earlier in the year. It is conceivable that the 70 CM antenna had been mounted prematurely on the spacecraft for some time and damaged while the satellite was in storage. The satellite deployed and we were pleased to discover that the satellite could still 'hear' 70 CM uplink

transmissions with just the antenna 'stub' attached to the satellite, though clearly not as well as if the antenna had not been damaged. An example of a linear transponder exchange between two amateur radio stations in South America (PY5LF in Brazil and LW3DRH in Argentina) may be found on You Tube: http://www.youtube.com/watch?v=LQ-DQNYrxAU&list=UUCJOzTz_VHCLItu6FYK--VA&index=6&feature=plcp

Another successful outcome was the use of the four cameras that provided imagery for the SSTV downlink. The four small commercial off-the-shelf surveillance cameras from Hunt Electronics successfully captured imagery throughout the mission and survived the rigors of space. The significant interest in the SSTV imagery is reflected by the high number of SSTV images that users uploaded to the ARISS SSTV Gallery (3,592).

The creativity of the AMSAT engineering team is reflected in the mounting of the SMEX solar panels on the space frame. Because the solar panels have a different thermal coefficient than the aluminum space frame, a method had to be found to secure the solar panels to the frame but allow enough 'give' to allow the solar panel and its support structure to expand and contract independently. The solution was found using 'Velcro' that provides enough holding power to keep the panels in place but allowed for differences in expansion. To our knowledge, Velcro has never been used for permanent mounting of external hardware on a space frame before; this imaginative solution to an engineering problem resulted in a new type of application not previously used on a spacecraft.

Perhaps the most significant technical achievement of the mission was the collection of telemetry for both the spacecraft and Kursk experiment by hundreds of amateur radio stations around the world and having that data forwarded to a central internet server site. Both the number of stations involved with data collection and the geographic dispersal of those stations resulted in a steady stream of data collection throughout the mission. As ARISSat-1 is a prototype spacecraft designed to place student payloads in low earth orbit, this successful collection of data during this mission vindicates the data collection model of using volunteers on the ground to collect telemetry and using the internet to forward that data to a central site.

A total of 295 ground stations submitted telemetry between deployment and de-orbit. The last telemetry was received at 0602 UTC on 4 JAN 12, shortly before de-orbit. Here is a summary of Internet Telemetry Server statistics:

Total ground stations reporting telemetry since deployment:	295
Total telemetry frames since deployment:	139,959
Total Kursk frames since deployment:	125,513

Grand total of all telemetry frames received by the server since deployment: 266,472

Given that data collection could not take place while the satellite was in eclipse following the failure of the Orlan battery, one can only imagine the significantly increased amount of data that could have been collected had the satellite operated in darkness. Since most people are away from their homes during daylight hours due to work or school, it is very likely that this data was collected by stations that were operating in an automated

mode, steering antennas and tuning radio receiver equipment by local computer which allows data collection activities to take place without the presence of the operator.

The final digital data received was jointly copied by Mori Seiji, JA8TCH of Sapporo City, Japan and Tetsoru Satou, JA0CAW of Niigata City, Japan at 06:02:14, 4 JAN 12, less than an hour before the estimated de-orbit of the spacecraft over the South Atlantic. Their data, combined with the submissions of many others, constitutes the most comprehensive coverage of the de-orbit of any amateur radio satellite. Both JA8TCH and JA0CAW received a certificate for their achievement from the ARISSat-1/KEDR Engineering Team.

The following summary of breakdown of individuals providing telemetry data to the central server by country is based upon the call sign prefix of the station providing the telemetry and/or their country as listed on qrz.com, an amateur radio website. The top ten countries as measured by the number of stations providing data are:

United States:	91
United Kingdom	36 (Stations from England, Guernsey, N. Ireland, Scotland, Wales)
Australia:	23
Japan:	19
Germany:	18
Italy:	13
France:	11
Canada:	5
Spain:	4
Belgium:	4
Total:	224 (76% of total stations providing data)

Total number of stations: 295

A total of 38 countries (Where the United Kingdom is counted as one country) are represented in this summary with the remaining nations having 1-3 stations each.

From an actual data collection perspective, the totals are very different as New Zealand, Sweden, Thailand and Brazil pop into this list. The top ten countries as measured by telemetry frames collected are:

United States:	88,884
United Kingdom:	17,386
Australia:	22,030
Japan:	39,906
New Zealand:	17,190
Germany:	10,161
Canada:	7,921
Sweden:	7,711
Thailand:	7,654
Brazil:	7,068

Total of top 10: 225,611 frames (85% of total frames received)
Grand total: 266,472 frames

France (5,837 frames) and Russia (5,696 frames) also did well. Given the few number of stations in several of these countries that provided data, clearly those individuals that did provide telemetry data were focused on it.

There were two sources of data telemetry that did not include their amateur radio call sign in the data that was forwarded to the ARISSat-1 telemetry website. This may reflect individuals who are not amateurs or that these are hams who may not have realized that they were supposed to configure the telemetry software to include their call sign. Since a call sign was not provided, we don't know where these two sources are located; they provided 1,324 frames of telemetry.

This strong support by amateurs around the world suggests that there is strong interest in supporting educational payloads where amateurs can assist in the data collection effort.

Technical Issues

On 10 AUG 11 the Orlan Spacesuit Battery began to show signs of failure as the satellite started to reset once in eclipse. This pending failure was expected. The Orlan Spacesuit Battery is designed for use with Russian spacesuits during EVA where the battery is meant to fully discharge and is limited to five charge cycles. It is not designed for repeated charge/discharge cycles typically found with spacecraft. The Silver-Zinc battery's limited charge cycles is why it wasn't recharged once it discharged onboard the ISS until just prior to deployment.

RSC-Energia insisted that the Orlan Spacesuit Battery be used because it was rated for use on the ISS and the original design called for use of an Orlan Spacesuit (Suitsat-2). In addition, the Silver Zinc battery technology is considered inherently safe for manned missions which eliminated a potential safety hazard.

The subsequent loss of the battery had a major impact on subsequent satellite operations however. Fortunately, the battery failed with an "open" condition, meaning that the failed battery did not interfere with the ability of the solar panels to power the satellite systems when in sunlight. However, in this situation the satellite system "resets" each time power is lost in eclipse, forcing the 15 minute timer system to restart once power is restored when the satellite returns to sunlight, reducing the amount of time the satellite is fully operational in sunlight. This also means that data collection for the Kursk experiment is lost each time power is lost. As the data collection process for the Kursk experiment specified data collection for one complete orbit followed by downlink of that data for the next 23 hours, the loss of the battery effectively ended the experiment since data for one complete orbit could never be collected nor could the data be retained through eclipse once power was lost.

Education Impact

The ARISSat-1 project is certainly unique as it incorporated some degree of student involvement prior to deployment, during the mission itself, and we expect following de-orbit as telemetry and Kursk Experiment data are posted and the performance of ARISSat-1 can be evaluated by students, teachers and others.

Preparations conducted during the construction phase included recording of student greetings and 'secret words' to be incorporated in s SD memory card. A request was made of the various AMSAT organizations around the world and the national radio clubs that make up the ARISS-I (Amateur Radio on the International Space Station-International) to submit voice recordings of students speaking in their native languages various greetings. Through the assistance of AMSAT organizations in the US, Europe and Russia, a total of 24 students participated in such recordings which were subsequently sent electronically to Dave Jordan, AA4KN for incorporation into the student greeting process.

In addition, students in the US (from Michigan, Florida and Pennsylvania) coupled with student submissions from Canada, Portugal, UK, Ireland, Sweden, Australia, and Switzerland submitted photographs and other documents in a "Fly a File" campaign for ARISSat-1. These files were incorporated into the SD card that contained the student voice greetings. A total of 123 students participated in the 'Fly a File' campaign. In addition, the daughter of AA4KN (Rebecca Jordan) recorded the satellite's voice ID and helped in the assembly. One of Dave's wife's students recorded the voice telemetry files that provided the basis for transmission of the telemetry values on the FM downlink. All together, a total of 149 students were involved with providing materials to be incorporated into ARISSat-1.

During the mission itself, students and teachers took advantage of the satellite's capabilities as time and circumstances allowed. AMSAT is not in position to provide a systematic process for measuring student impact, but anecdotal evidence suggests that motivated teachers did indeed incorporate ARISSat-1 into their educational activities. These activities include the following:

- Jim Cook of Sleepy Hill Elementary School in Lakeland, FL reports that an estimated 800 students were exposed to ARISSat-1 project from four area elementary schools in Polk County, FL both prior to the deployment (October 2010) as well as during mission operations (October 2011). This included information about the satellite that was broadcast on the local school TV system. About 50 students made several attempts to listen to the spacecraft in September 2011 but were unsuccessful, apparently due to use of inadequate equipment.
- Matt Severin, N8MS is a Principal of Dowagiac Middle School, MI who had 17 students involved with telemetry data collection from ARISSat-1 in September. Their activities are noted in a newspaper article that can be found here: <http://www.dowagiacnews.com/2011/09/13/passionate-principal-stokes-science-interest/>

- Patty O'Mechair, EI7GK in Ireland noted that 96 students in his school (Gaelcholáiste na Mara) listened to a broadcast interview that he did about ARISSat-1 on Raidió na Gaeltachta, a national broadcast radio station in the Gaelic language.

Overall, the documented involvement of students with ARISSat-1 noted in this section of this report in the preparation of materials for flight and during flight totals 1,103 students.

ARISSat-1 Questionnaire

Steve Bible, N7HPR conducted an "ARISSat-1 Operational Survey" to gauge interest in the features in ARISSat-1. He used "Survey Monkey" as medium for conducting the survey. Anyone who had any experience using ARISSat-1 was encouraged to participate in the survey. Word of the survey was spread through various means, including postings on AMSAT-BB, ANS Bulletin items, and incorporated into his EE Times blog, noted earlier. The survey began on 22 SEP 11 and two weeks worth of responses were incorporated into a paper that Steve wrote that was published in the Proceedings of the AMSAT-NA 29th Space Symposium and Annual Meeting ("ARISSat-1 Operational Survey", pp. 25-28). Steve also gave a presentation at the Symposium (4-5 NOV 11) using updated statistics, but the overall findings were not changed by the additional responses that were built into Steve's paper.

More than 600 people completed the survey that was the basis for Steve's statistical compilation. 97% of the respondents had heard the satellite directly with 88% of respondents describing their experience listening to the satellite as "enjoyable/exciting". About 63% of the respondents listened to the greetings from space, 51% of the respondents captured SSTV images and 21% captured digital telemetry. Of those that took the survey, 57% reported that they did not submit listening reports. This suggests to me that the number of certificates issued by AMSAT (1,450) probably means that the number of individuals on the ground who actually heard the satellite was significantly higher, perhaps at least 3,550 (1450/.57). This 3,550 minimum would not reflect those who perhaps heard the satellite in a group setting (such as at a school, amateur radio club meeting, etc.). A number of respondents stated that they submitted video to YouTube/Vimeo (43% or 258 respondents, which is below the number of videos available online).

Respondents also were asked if they shared their ARISSat-1 experience with children. The results were:

60% - Not Yet.

30% - Yes, with my kids. This suggests 180 respondents touched at least one child with ARISSat-1.

5% - To my youth group (for example: Scouts). This suggest that 30 youth groups were impacted by ARISSat-1.

3% - Yes, to a class (Primary, Secondary). This suggests that 18 classrooms were impacted by ARISSat-1.

2%- Yes, to a class (University). This suggests that 12 university classrooms/groups were impacted by ARISSat-1.

What these numbers also suggest is that the anecdotal evidence of student/children impact given in the “Education Impact” section of this paper likely understates the actual impact of the ARISSat-1 mission. If one presumes 30 students per class/youth in the K-12 gathering, it is likely that an additional 1,440 students/youth (30 students x 48 groups/classroom) were exposed to ARISSat-1 activities of some type. Adding this count to the previous total plus including the 180 children who experienced ARISSat-1 with their parent(s) raises the minimum number of ARISSat-1 students ‘touched’ to about 2,729 students.

We should also recognize the impact of ARISSat-1 on adults can also be significant and that the satellite likely assisted in the “life long learning” experience as well. While it is not clear how many adults may not have had previous experience with amateur radio satellites, it would be fair to state that the interest generated in this satellite likely resulted in more people than ever taking the time to listen for an amateur radio satellite. The process of learning the basics of knowing when the satellite would be in range, preparing the equipment of reception, and experiencing the thrill of a successful ‘encounter’ with ARISSat-1 is just as valuable to that individual as the student’s experience in learning about satellites and wireless communication.

Post-Mission Development

With the de-orbit of ARISSat-1 on 4 JAN 12, AMSAT has focused on providing telemetry data that can be easily accessed and manipulated by students and others wishing to evaluate the performance of the spacecraft. As of 4 FEB 12, all of the telemetry from ARISSat-1 that was submitted over the Internet to the telemetry server has now been decoded and converted to comma separated variable (CSV) format. These files can be imported into most spreadsheet programs. The data in the CSV files is the decoded data after applying the telemetry equations to the raw spacecraft telemetry.

All of the decoded CSV telemetry files are currently available at <ftp://amsat.org/amsat/telemetry/arissat/stp-decoded/> and the exact same files are also at <http://www.amsat.org/amsat/ftp/telemetry/arissat/stp-decoded/>

A link to these same datasets will be made available on the www.arissat1.org website as well. These datasets provide an opportunity for students, teachers and other interested parties to evaluate spacecraft performance, including power production, temperatures of key components, and system health. Spin rates, for example, can be extrapolated from such data as well as determine which solar panels were producing

power at any particular time. This data will be augmented over the next few weeks as additional steps are taken to:

- Add KURSK telemetry
- Add additional telemetry that was submitted by email
- Duplicate telemetry removal

Eventually, we expect that as this data is analyzed, users will share their analysis that could become the basis for developing teaching aids.

Student Engineering

As noted previously, a major shortcoming of ARISSat-1 was the Russian Orlan Silver Zinc Battery that failed about one week after deployment. This battery was placed in service in a manner for which it was never designed and failure was expected given this misapplication.

AMSAT is now working with students at Penn State University, Erie on the development of a super capacitor package to serve as a replacement for the Orlan Battery in the event that another ARISSat –class spacecraft is flown. These senior engineering students are working on their ‘capstone’ project during the 2011-2012 academic year with the goal of having a prototype developed by May 2012. Prior work with super capacitors by SUNY-Binghamton engineering students under a capstone project for AMSAT have demonstrated the high storage capacity, high number of charge cycles and high degree of retention of capability over long term use that super capacitors provide.

This development work is another reflection of how the ARISSat class satellite provides student involvement in space hardware under AMSAT projects. Should an ARISSat-2 mission ever be approved, flying a super capacitor to provide power storage would be one way to increase the educational impact of such a mission. When AMSAT built ARISSat-1, it also built a flight backup and two additional spacecraft, including space frame and associated electronics. Given the degree of development already accomplished, these spacecraft could be prepared for flight relatively quickly.

Summary

As a prototype of a new class of amateur radio satellites, ARISSat-1 was a technical success that the ARISSat-1/KEDR team can take pride in. The technology demonstration was highly successful and the satellite provided reliable service throughout its five-month mission. The success of the technology introduced in ARISSat-1 will undoubtedly be applied to future spacecraft as the SDX, MPPTs, and BPSK-1000 all worked well.

From a student payload perspective, ARISSat-1 clearly demonstrated the potential for receiving payload and satellite telemetry through a worldwide collection effort by amateur radio stations. A total of 295 stations in 38 countries supported this effort. We also recognize that in the future, provisions must be built into the data collection effort

that in the event of loss of battery power that would prevent operation of the satellite in eclipse, the ability to collect data is not lost when the satellite goes into eclipse.

Along with the technical success, AMSAT's efforts to incorporate features in support of educational outreach also generated significant interest. For the first time, AMSAT developed software packages in support of a specific satellite opportunity, making that software (telemetry download software for two operating systems) available when the satellite deployed. A new website (www.arissat1.org) was created to support the mission, providing links to the software packages for Windows and Macintosh platforms.

Ground user interest was clearly intensive given the degree of social media content generated, the number of certificates applied for, and the number of 'hits' that social media created.

The numbers of students impacted by ARISSat-1 was likely to be at least 2,729 given the documented measurement of 1,109 noted in the "Education Impact" section, the likelihood that an additional 1,440 or more students were involved given the number of school classroom/youth gatherings estimated to be involved by those that took the ARISSat-1 Operations Survey conducted by Steve Bible, N7HPR, plus the 180 (minimum) who experienced ARISSat-1 with their parent(s) as reported in the survey. Further, since we don't know what activities took place in Russia and the CIS, it is conceivable there were additional school impacts as well given RSC-Energia's interest in designating the satellite "Kedr" (Yuri Gagarin's call sign) and the 50th anniversary commemoration of his flight in 2011.

Just as important, the experience with ARISSat-1 has caused AMSAT and the ARRL to re-examine how amateur radio satellites may be better used to support STEM in the classroom and determine what materials might be helpful to educators. AMSAT now has a VP-Educational Relations tasked with creating a team within AMSAT to support educational objectives. AMSAT recognizes that educational outreach is critical in terms of finding launch opportunities as the cost of launches continue to rise and that amateur radio satellites must support educational goals in order to find launch opportunities. As an all-volunteer organization (AMSAT's only employee is the office manager), AMSAT must find ways to attract volunteers willing to create materials in support of educational objectives as part of a satellite project.

Space Symposium 2012

AMSAT *Fox* Satellite Program



Tony Monteiro, AA2TX

Background



- AO-51 was the most popular ham satellite
- Could be worked with simple equipment - HT and "arrow" antenna
- Widely used in scouting, educational and demonstration events
- Failed in November 2011
- Need replacement ASAP!

Background (cont)



- Good old days of free launches for AMSAT are gone
- Microsats once a low-cost path to orbit
- Commercial launch costs are > \$1M
- AMSAT cannot afford to launch a microsat

3

AMSAT *Fox* Launch Strategy



- Take advantage of large and growing interest in CubeSats
- Develop family of CubeSats that have ham radio transponders and are capable of hosting science experiments
- Partner with universities to develop science and education missions
- Launch provided by primary mission via grants or NASA ELaNa program
- After primary mission completed, satellite provides amateur radio transponder

4

CubeSat Technical Challenges



- Very small size (4-inch cube)
 - $\frac{1}{16}$ volume of AO-51
- Mass limit
 - 1.33 kg
- Limited space for solar cells - limited power
- Limited area for antennas

5

Fox Program Phases



- Phase 1 satellites
 - 1U CubeSats
 - FM analog transponder
 - Digital data up to 9600 bps
- Phase 2 satellites
 - 1U to 3U CubeSats
 - Software defined radio transponders
 - Linear and high-performance digital modes

6

Fox-1 Satellite



- Proposal submitted to NASA for launch as an educational mission - Nov 2011
- Penn State student experiment with MEMs gyros
- Requested orbit - 650 km ("A Train")
- Requested launch - 2nd Half 2013
- Accepted into NASA ELaNa program - Feb 2012

7

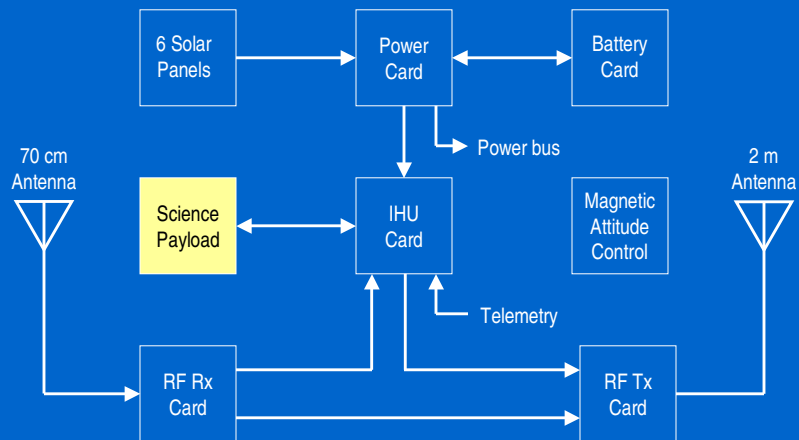
Fox-1 Satellite Overview



- Transponder Mode
 - FM analog repeater
 - Telemetry sent simultaneously with voice in sub-audio band as low-speed FSK
- Data Mode
 - FSK Digital data up to 9600 bps
 - Will be tested on-orbit for use in future missions

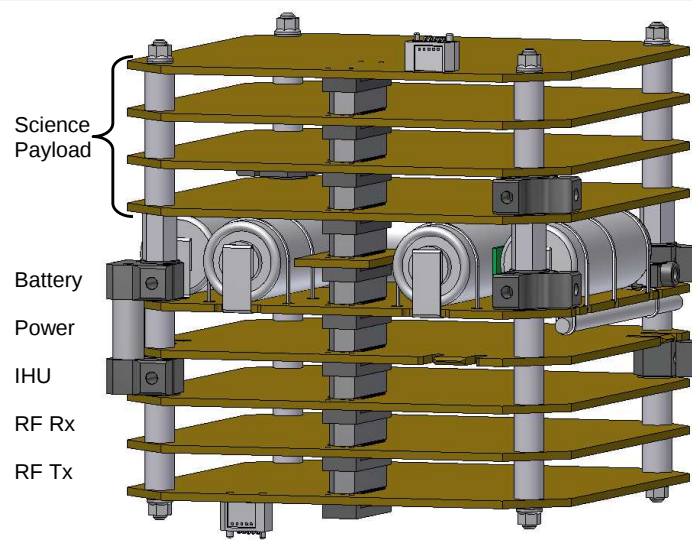
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Fox-1 Avionics

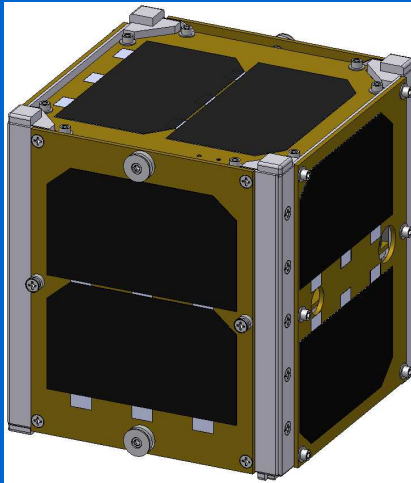


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Avionics PCB Stack



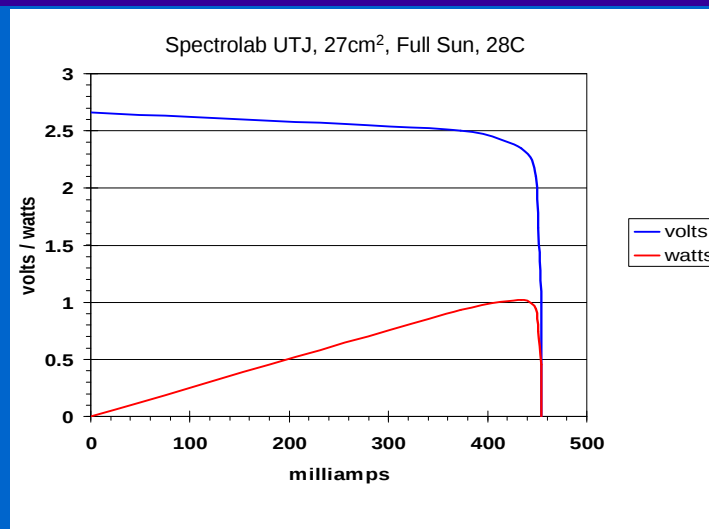
Solar Panels



- 6 solar panels
- 2 cells per panel
- Spectrolab Ultra Triple Junction cells
- Space-rated
- 28% conversion efficiency

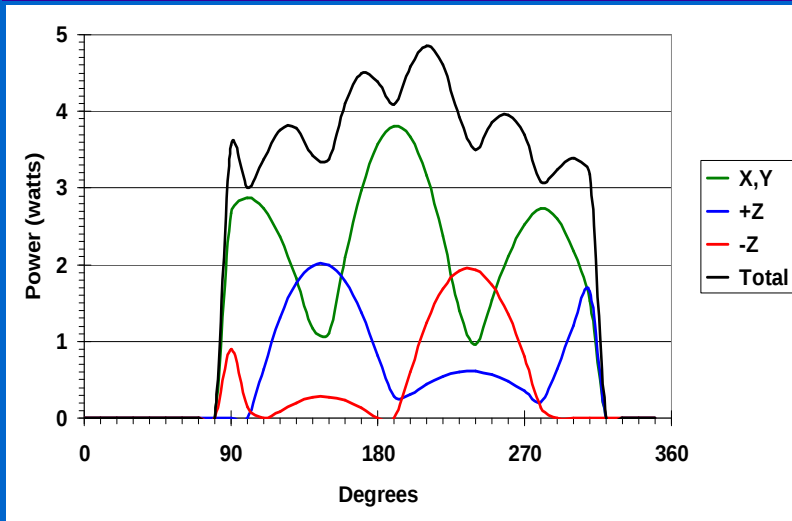
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Solar Cell Characteristics

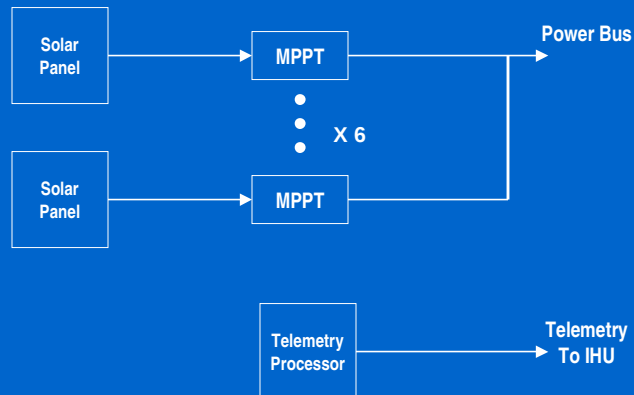


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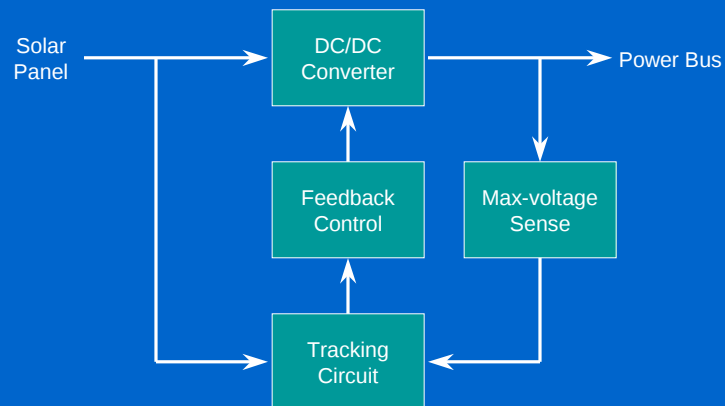
Generated Solar Power



Power Card

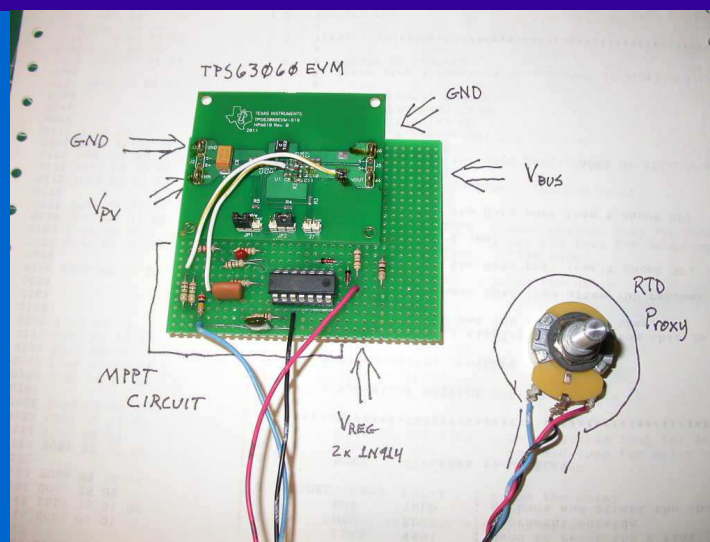


MPPT Operation



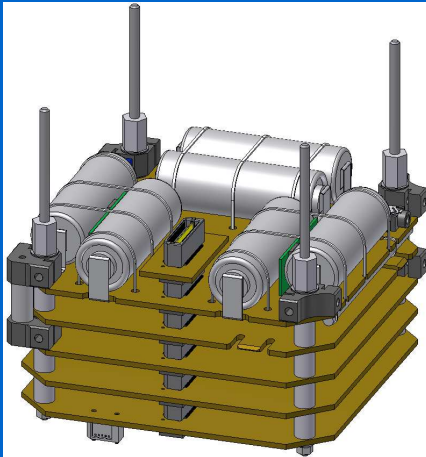
15

MPPT Test Circuit



16

Battery Card



- 6 Cadnica (NiCad) A cells
- 3.6 V nominal
- 12 watt-hours capacity
- 10% depth of discharge for long life
- Battery protection circuitry
- Active thermal control
- Telemetry processor

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IHU Card



- Collects telemetry information
- Operates science experiment
- Sends telemetry as sub-audible low speed FSK in transponder mode
- High speed FSK in data mode
- Executes commands from ground control

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IHU Card (cont)



- ST Microelectronics STM32L
- Ultra low power CPU
- 32-bit processor
- 33 MIPS
- 128K FLASH program memory
- 16K RAM
- 64K non-volatile FRAM
- Micro-SD card
- MEMs gyros

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IHU Software



- Open source SW tools (GNU C compiler)
- LINUX or Windows development environment
- FreeRTOS operating system
- STM32 "Discovery" card for SW development
- FreeRTOS running on Discovery card
- Drivers for I²C, SPI, serial ports running
- Modems for high and low speed data will be done in software

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RF Rx Card



- 70cm FM receiver
- LNA with SAW filter
- Automatic frequency control
- Provides audio to IHU and RF Tx
- 67 Hz PL tone detector
- 2 minute timer to key RF Tx

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RF Tx Card



- 2 meter FM transmitter
- Audio inputs from IHU and RF Rx
- Audio processing (deviation limiter, filters, mixer etc.)
- True FM exciter
- Power amp produces > 400 mW

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RF Power Amp



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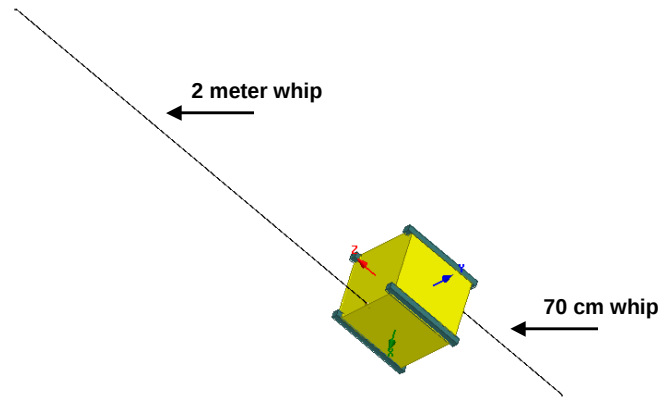
Attitude Control



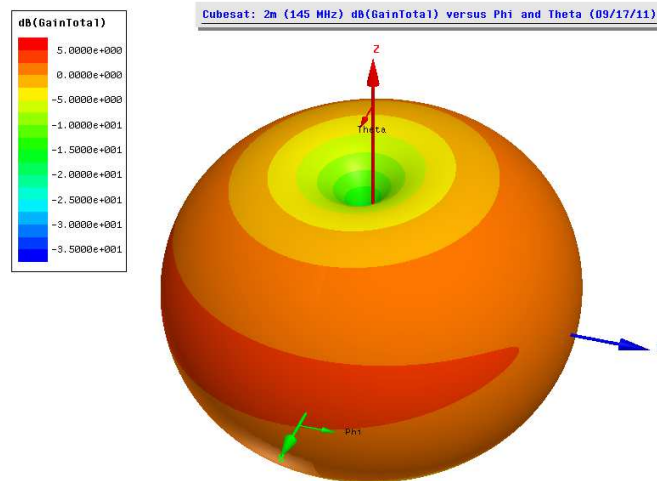
- Passive magnetic system
- Aligns satellite z-axis with earth's magnetic field
- Bar magnet on structure
- Hysteresis rods on battery card for motion damping

24

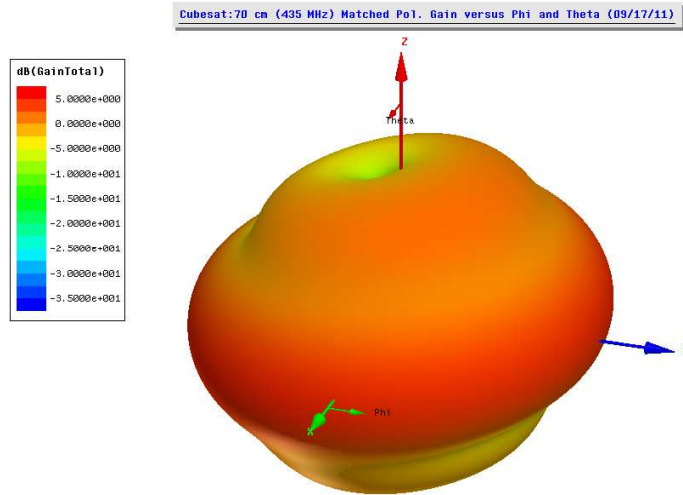
Antennas



VHF Antenna Pattern

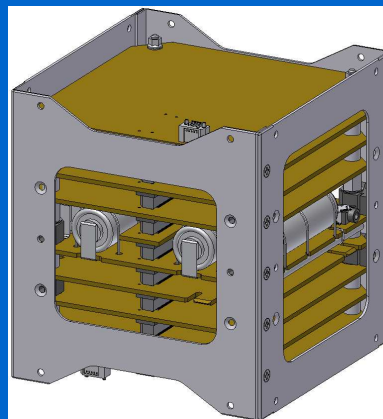
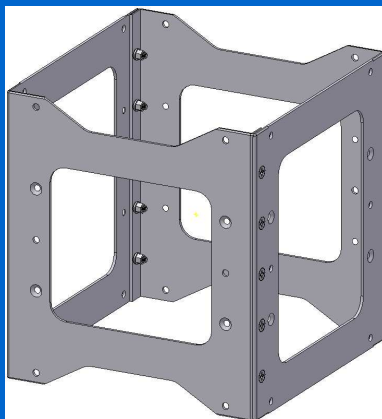


UHF Antenna Pattern



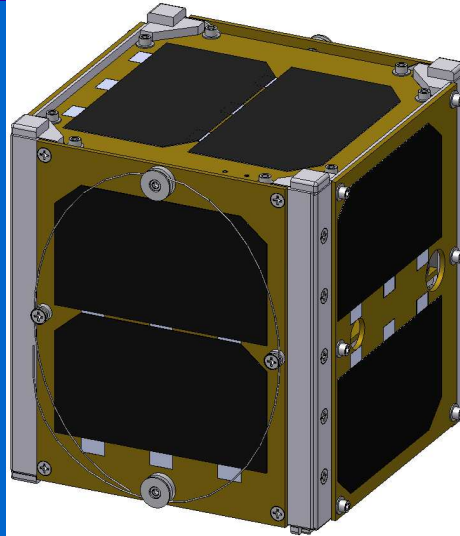
27

CubeSat Structure and PCB Stack



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Assembled *Fox-1* Satellite



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Satellite Projects based on *Fox-1*



- AubieSat-2 & 3
- RadFxSat

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AubieSat-2 & 3



- Two CubeSats
- Proposal for National Science Foundation grant
- Auburn, University of Alabama & AMSAT
- 1-year science mission - atmospheric physics
- Ham transponder after science mission is complete

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AubieSat-2 & 3 (cont)



- Alabama to provide science payload
- Auburn to provide 3U structure and gravity gradient boom
- AMSAT to provide avionics based on *Fox-1*
- Proposal submitted
- Response from NSF expected in November
- NSF grants are highly competitive!

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RadFxSat



- Vanderbilt University and AMSAT
- 1U CubeSat
- Based on *Fox-1* (flight spare)
- Science payload provided by Vanderbilt
- NASA ELaNa proposal

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RadFxSat - Science Mission



- Advance the state of the art in understanding the effects of space radiation on electronic components
- Demonstrate an on-orbit platform for radiation qualification of components for space flight
- Validate and improve computer models used to predict radiation tolerance of semiconductor manufacturing processes

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RadFxSat - Secondary Mission



- Formal STEM education of university undergraduate and graduate students at Vanderbilt University
- Formal STEM education of high school teachers and students at Vanderbilt University
- Informal STEM education via amateur radio transponder operation

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RadFxSat - Mission Profile



- Science mission runs simultaneously with amateur radio transponder
- Science data transmitted via low-speed downlink
- Requested launch 2H 2014
- Requested orbit - 650km (same as *Fox-1*)
- NASA ELaNa proposal due Nov 12
- Response expected Feb 2013

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AMSAT Classifieds



*** HELP WANTED ***

AMSAT is always hiring!

- **Design engineering:** mechanical, electrical, PCB design systems, software, project management, thermal design
- **Satellite construction:** PCB construction, parts procurement, component fabrication, assembly
- **Satellite testing:** environmental testing, functional testing, requirements and regulatory compliance testing

Contact Tony Monteiro aa2tx@amsat.org

7

Any Questions?



AMSAT Space Symposium 2012

Space Radiation Mitigation for *Fox-1*



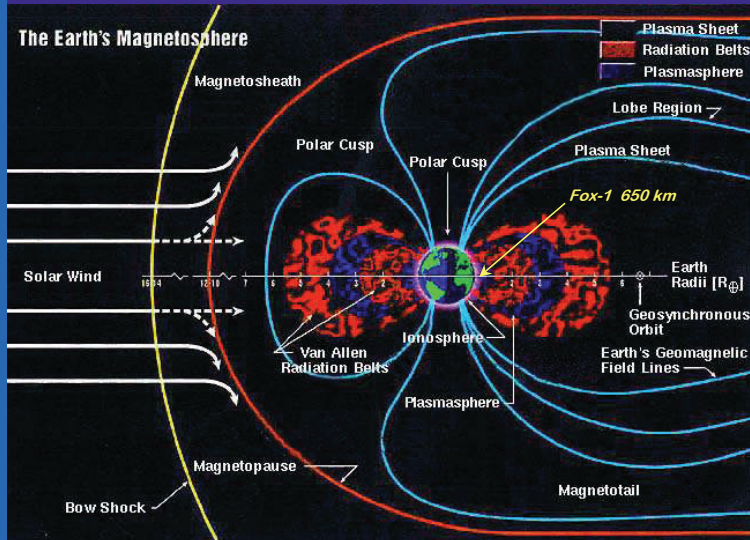
Alan Biddle WA4SCA
Tony Monteiro AA2TX

Space Radiation Components



Type	Source	Composition
Trapped Particles in Van Allen Belts	Solar Wind	High Energy Protons (+ Anti-protons!) High Energy Electrons Bremsstrahlung (X-Rays)
Galactic Cosmic Radiation	Cosmic Rays	Hydrogen to Uranium Nuclei Low Flux, but Very High Energies
Solar Particle Events	Solar Flares and Coronal Mass Ejections	Energetic Electrons, Protons, Alpha Particles

Radiation in Orbit

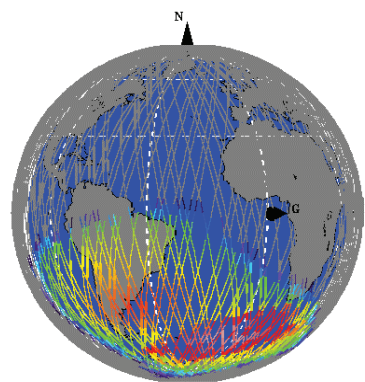


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South Atlantic Anomaly



- Earth's magnetic field non-concentric with rotation axis causing Van Allen belts to dip down to 200 km



- The major source of space radiation for *Fox-1*

4

Space Radiation Effects



- Total Ionizing Dose (TID)
The result of all of the radiation that is absorbed by a component over time. Non-deterministic but expected ranges can be effectively modeled.
- Single Event Effects (SEE)
The result of high energy particles. Can happen at any time - on first day or after many years in orbit.

5

Radiation Effects on Components



- Total Ionizing Dose (TID) causes components to gradually deteriorate like wear on a tire
 - Parameter drift
 - Electrical leakage in insulators
- Single Event Effects (SEE) cause immediate failure like a tire blowout from a sharp object
 - Failure can be temporary or permanent
 - Transient signals
 - Stuck-bits in logic devices
 - MOS gate rupture
 - CMOS latchup (SEL)

6

TID Modeling



- The radiation source model
Various models applicable to different particles and solar conditions which each give significantly different results - picking the right one is part art and part science.
- The orbit, and expected solar activity
Solar activity varies significantly over the short and long term - a Coronal Mass Ejection (CME) can deliver a years worth of radiation in a few days.
- The radiation absorption model used for the spacecraft components

7

Spacecraft Absorption Models

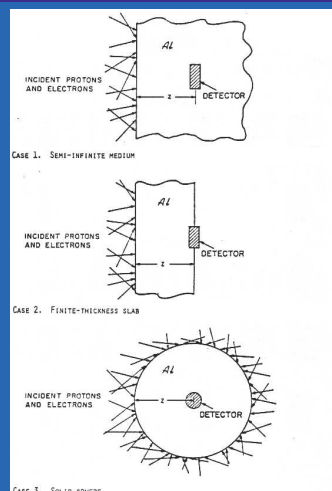


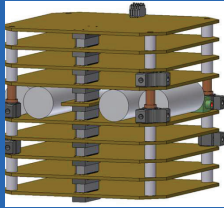
Illustration Courtesy of ESA/SPENVIS

No publicly available models for a complete, general spacecraft. There are three basic geometries available.

1. Semi-infinite slab - models components near surface of spacecraft.
2. Finite slab - models spot shielded components.
3. Solid spherical shell - models components deep within spacecraft.

8

Calculation of TID Radiation

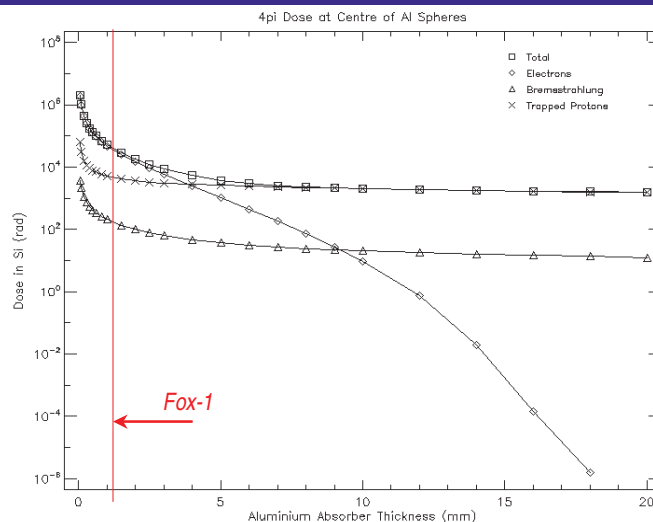


Given the *many* approximations, the spherical shell model is surprisingly applicable to most configurations.

- None of these models closely resembles a CubeSat. In order to develop a semi-quantitative profile for radiation deposition, select a radiation source profile and:
 - Pick the deposition model most appropriate to the satellite face.
 - Convert the component substances to the equivalent thickness of aluminum.
 - Calculate the radiation deposition between each surface and the opposite surface.
 - Superimpose the radiation contributions from each surface to get a *very* approximate 3 dimensional image.

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Fox-1 Effective Shielding



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Component Spot Shielding



- Tantalum or lead traditionally used for spot shielding of sensitive components to reduce TID
- Spot shielding can actually *create* additional radiation due to Bremsstrahlung
- Reductions in TID can result in an increase in SEE
- Use limited spot shielding of specific components if warranted

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ESA SPENVIS TID Model



- 5 year mission lifetime
- 650 km polar orbit
- Include average contribution of shielding from structure and PCBs
- Spherical shell model
- Model shows "high" confidence that typical internal component TID < 30 kRAD

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SEE Modeling



- Need to calculate the Linear Energy Transfer (LET) of a particle as it passes through components leaving a “contrail” of energy along its path.
- Single event effect occurs when energy deposited by a particle is above the component's $LET_{\text{threshold}}$
- Computer models require detailed component internal structure information - not a practical approach for AMSAT
- NASA data for LEO orbit shows low event probability above $\sim 30 \text{ MeV-cm}^2/\text{mg}$

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Overall Radiation Mitigation Strategy



- Satellite based on COTS parts
- Use radiation tested parts where possible
- Employ system-level radiation tolerance
- Very limited use of *rad-hard* parts
 - Solar cells are rad-hard
- Limited radiation spot shielding of specific components if warranted

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Radiation Mitigation *Reality*



- It is not possible to eliminate all risks
- It is not possible to use only proven, tested components
- Reduce risks where possible
- Use conservative circuit design approaches
- Design for fault tolerance

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Engineering Guidelines



- Prefer COTS parts that have been tested
 - TID > 30 kRAD
 - SEL > 30 MeV-cm²/mg
- Do not use parts that have tested poorly
- Space flight heritage - better than nothing
- Prefer discrete semiconductors to ICs
- ICs from TI tend to test well
- Untested or sensitive CMOS parts must have latchup protection circuitry (use FPF20xx)
- Passive components can generally be considered safe

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Low Risks



- U310 family J-FETs
- 2N2222 type transistors
- LM139 comparators
- LM6142 op amps
- LT6233 low noise op amps
- TMP36 temp sensors
- DS1631 I²C digital thermometers
- CD4000 & 74HCxxx logic generally OK

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High Risks



- Any version of 555 timer
- Any part with an internal charge pump
- All low-dropout voltage regulators and high-side switches with N-channel or NPN pass transistors
 - LP2941 - LP2953
- BiCMOS linear components (op amps)
 - LTC2052
- Active temperature sensors
 - AD590
- Untested microprocessors & microcontrollers

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NASA Derating Guidelines



PART TYPE	RECOMMENDED DERATING LEVEL
Capacitors	Max. of 60% of rated voltage
Resistors	Max. of 60% of rated power
Semiconductor Devices	Max. of 50% of rated power Max. of 75% of rated voltage Max. junction temperature of 110°C
Microcircuits	Max. supply voltage of 80% of rated voltage Max. of 75% of rated power Max. junction temperature of 100°
Inductive Devices	Max. of 50% of rated voltage Max. of 60% of rated temperature
Relays and Connectors	Max. of 50% of rated current

NOTE: Maximum junction temperature levels should not be exceeded at any time or during any ground, test, or flight exposure. Thermal design characteristics should preclude exceeding the stated temperature levels.

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Space Radiation Resources



- NASA JPL: radcentral.jpl.nasa.gov
- NASA Goddard: radhome.gsfc.nasa.gov
- ESA : escies.org/labreport/radiationList
- IEEE papers
- NSREC conference papers
- Alan Biddle WA4SCA - consulting radiation engineer

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Fox CubeSat Mechanical Design

Robert Davis KF4KSS and Steve Christie

Abstract

Fox 1 will be AMSAT's first 1U CubeSat, 100x100x100 mm (about 4x4x4 inches) with a weight of up to 1.33 kg (about 2.9 pounds) with 113.5 mm long rails. The bent aluminum sheet metal exterior structure will contain a ten stack of PCBs with the top four reserved for experiments. Each of the six faces of the cubesat will have a solar panel affixed. Two whip antennas will now be stowed on side panels, but after launch still extend parallel to +/- Z axis. Fox 1 mechanical design is expected to be fully designed and prototyped by the end of 2012. This paper describes the changes made in the mechanical design since last year.

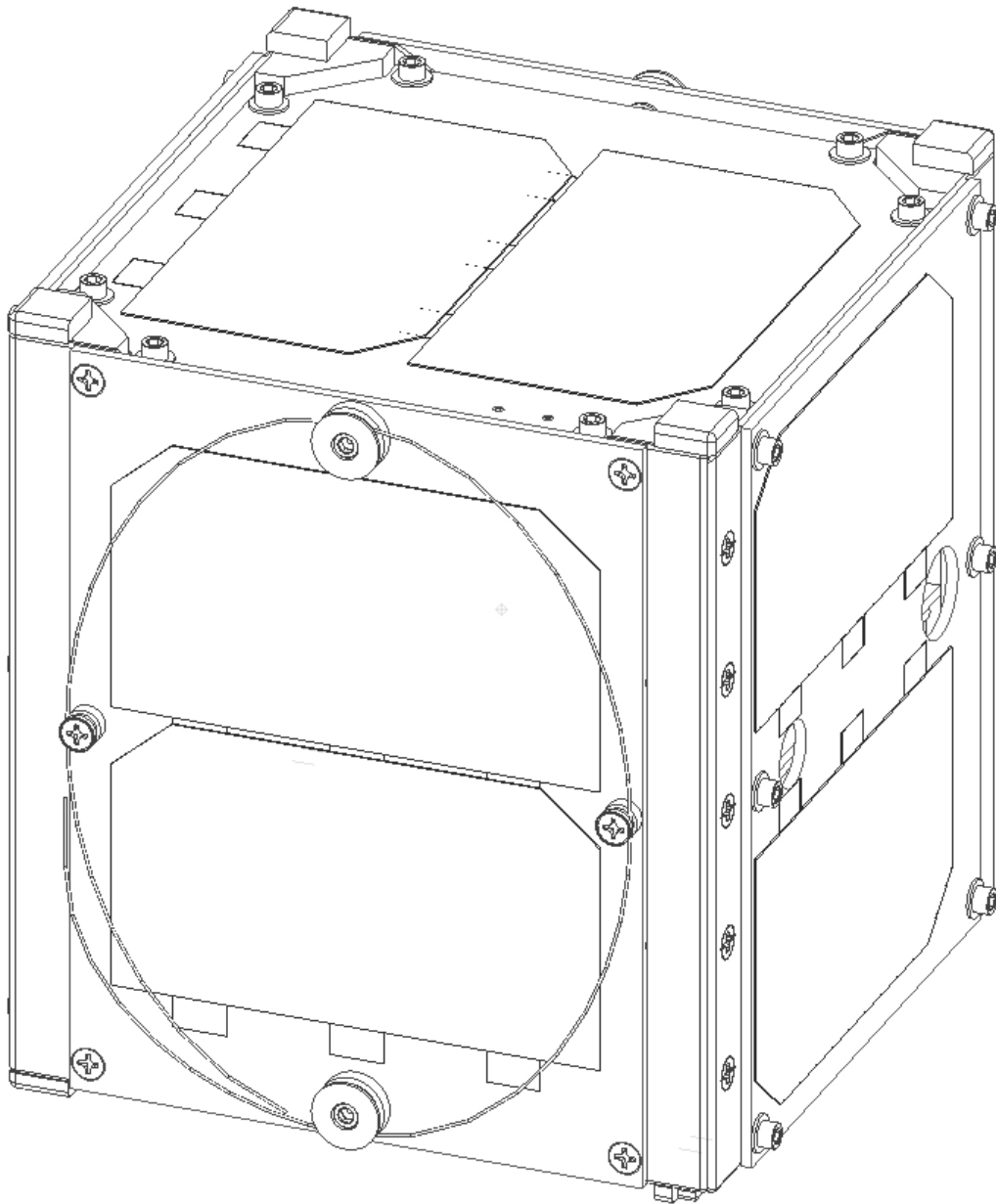


Figure 1 Fox1 stowed

Structure

The cubesat structure is bent aluminum sheet metal in order to offer greater volume for internal PCBs and to eliminate a number of fastener joints. Since last year, the two identical sheetmetal pieces are extended from 100mm tall to 108mm tall. After recessed fasteners and recessed sides of the Rail Ends are considered, the sheetmetal alone meets the 75% rail contact area requirement. The added length still fits within the allowable volume by reducing the heights of the Rails Ends on top and bottom.

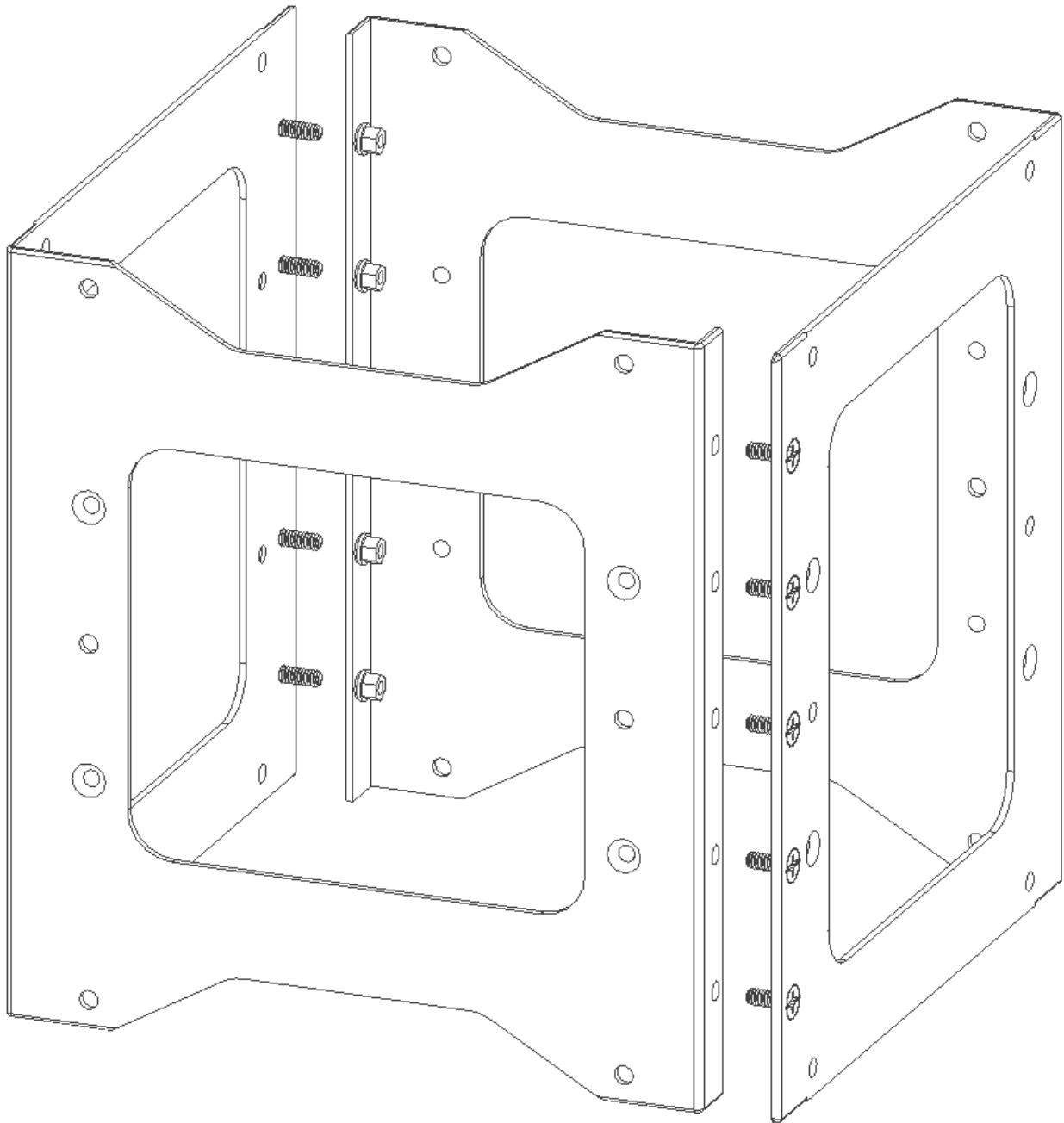


Figure 2 Bent Walls (exploded)

Two of the -Z Rail Ends hold spring plungers, specifically the part number specified by the CubeSat Design Specification. The other two -Z Rail Ends can accommodate contact switches, though only one of the two is baselined to fly.

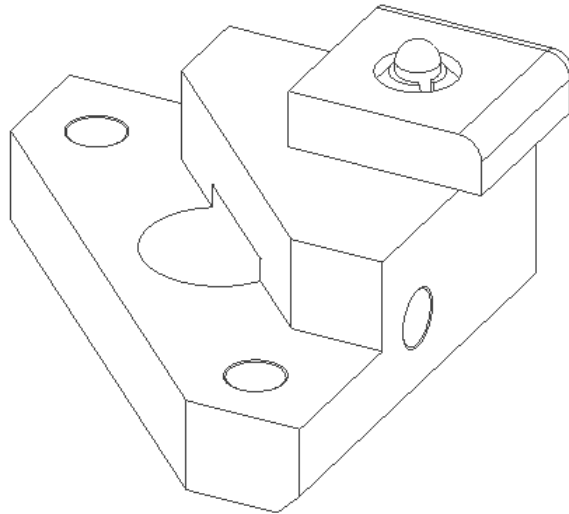


Figure 3 -Z Rail End with Spring Plunger

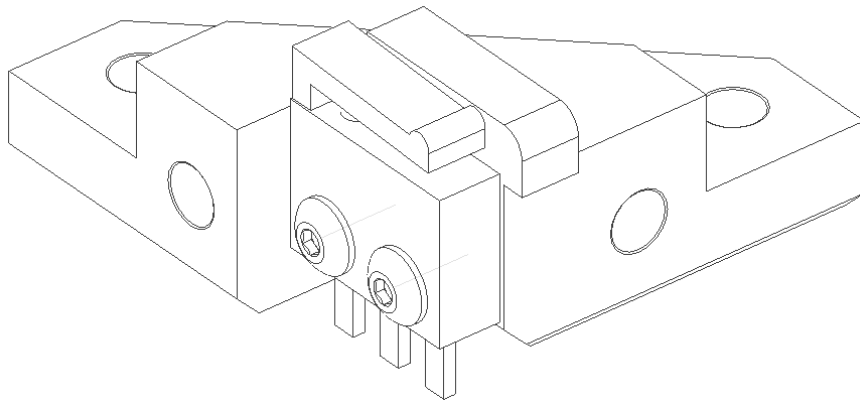


Figure 4 -Z Rail End with Contact Switch

Batteries

The four “C” sized batteries were changed to six Sanyo “A” KR-1700AUT batteries based on convenience to package. The six “A” cells have less capacity, but eliminate the need to deeply machine the battery circuit board. The battery board is in the middle of the PCB stack so that the combined center of gravity is inside the requirement set in the CubeSat Design Specification. The individual batteries are pushed to the perimeter of the circuit board to encourage spin stability around the Z axis.

Hysteresis Rods and Magnet

Similar to AO-51, the Fox 1 cubesat will spin about a permanent magnet. The magnet is a standard size, about $\frac{1}{4}$ ” diameter and 1” long. See Figure 6 and Figure 7. Two hysteresis rods are added to dampen oscillations. The hysteresis rods are also a standard $\frac{1}{8}$ ” diameter, and cut to about 3” long. They are mounted under the battery board, orthogonal to each other, and orthogonal to the magnet. See Figure 5.

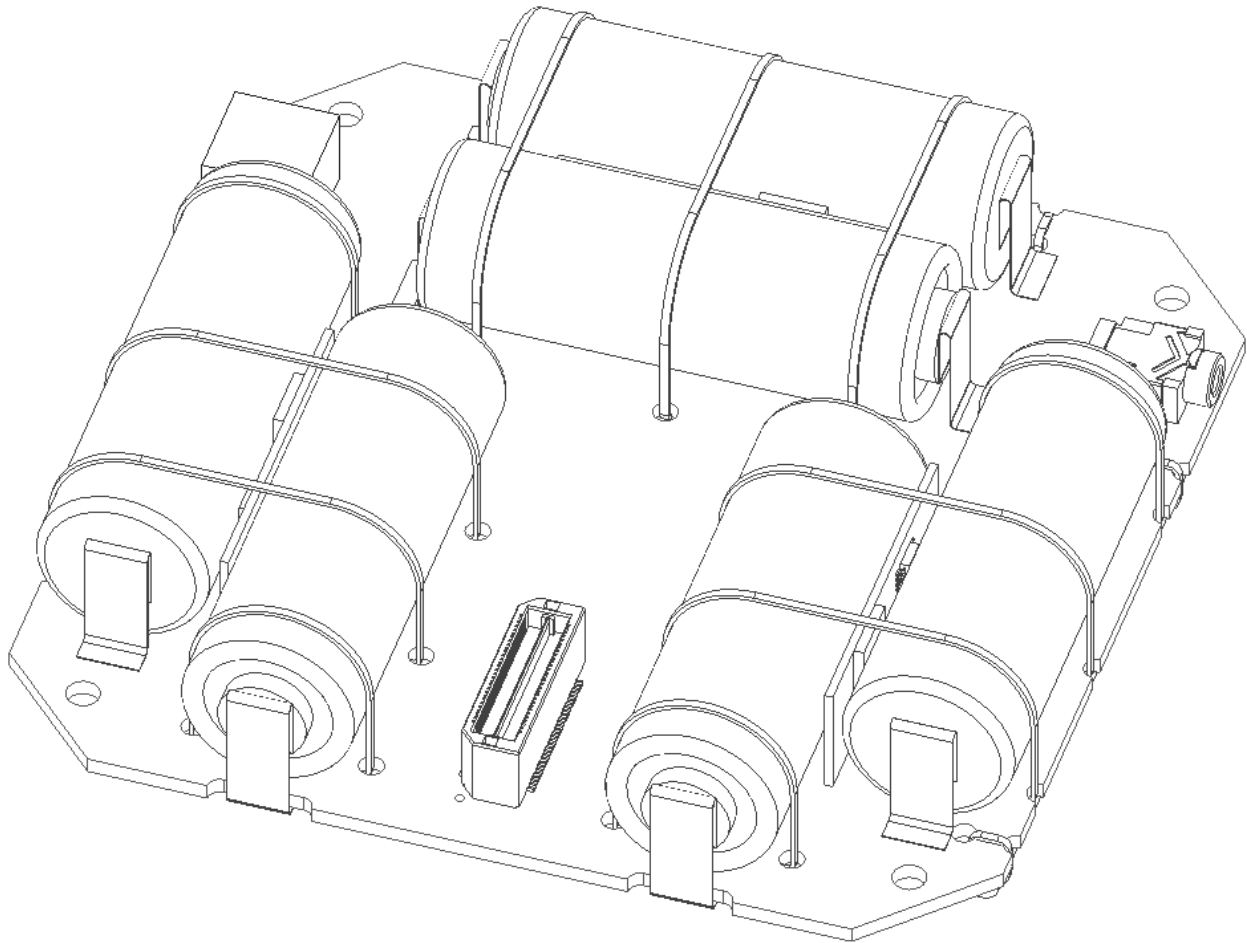


Figure 5 Battery Assembly

PCBs

The PCBs are a single stack of ten with the batteries centered and the top four reserved for experiments. The PCBs are stacked with long corner screws and spaced with aluminum spacers for electrical and thermal conduction. The gaps between all PCBs is 8mm To prevent heat leakage from the PCB stack to the colder structure and solar panels, Delrin blocks mount the PCB stack to structure. To keep the Delrin small, those aluminum spacers were swapped with copper so the diameter could be reduced. To accommodate potential tolerance buildup of the PCB stack height, The Delrin mounts can be adjusted slightly higher or lower by moving shim washers above and below.

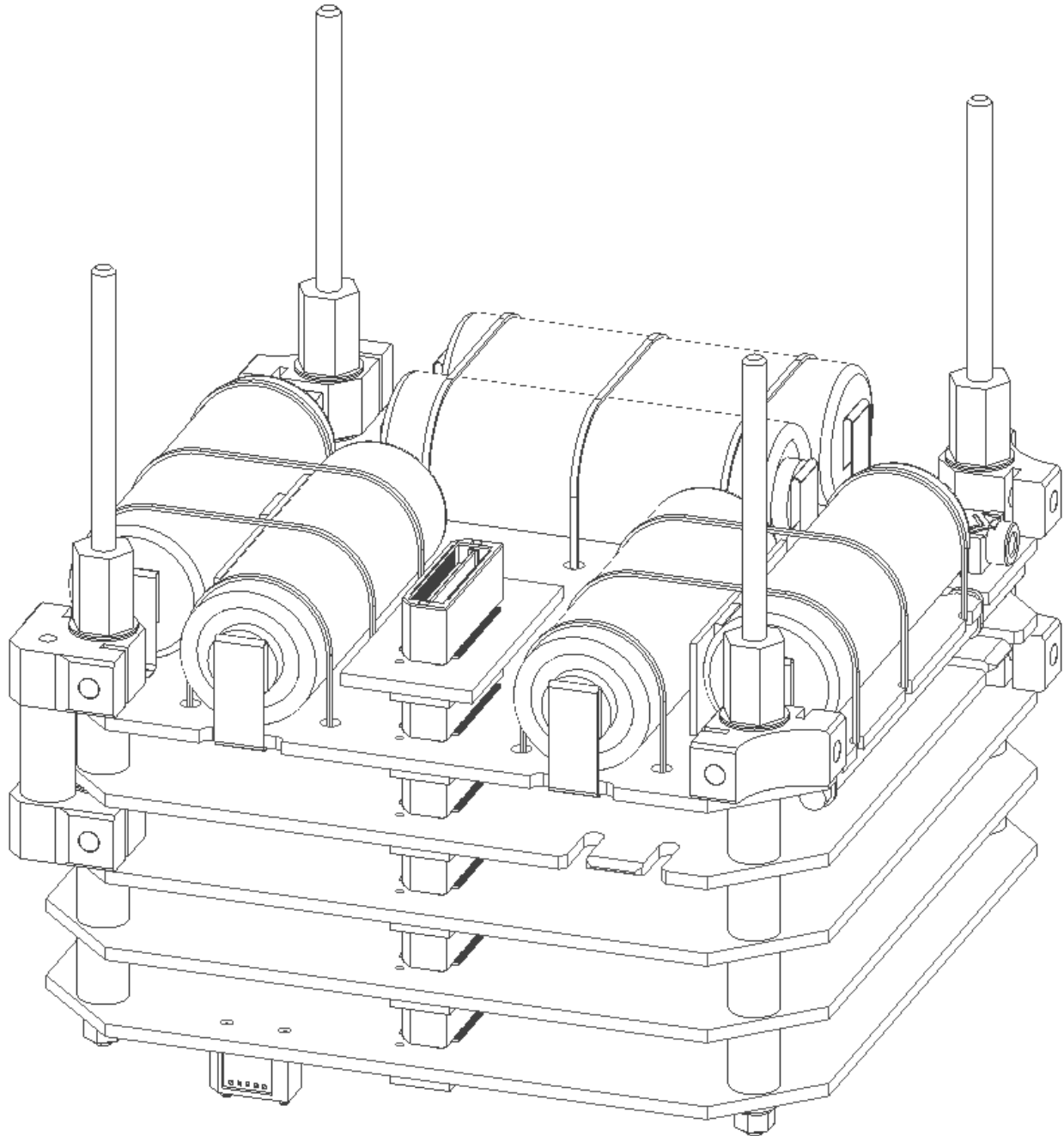


Figure 6 PCB Stack of Avionics

The PCB stack height happens to be about 88 mm. This makes it convenient to use 6mm tall connectors from the top and bottom of the PCB stack to the +Z and -Z Solar panels. To limit heat loss here, the pin count is kept to a minimum and the solar panels do not share the standoffs and corner screws. The side solar panels have a one-piece connector that allows each edge of the PSU card to attach as if it were an edge card. Again, to limit heat loss here, the pin count is kept to a minimum.

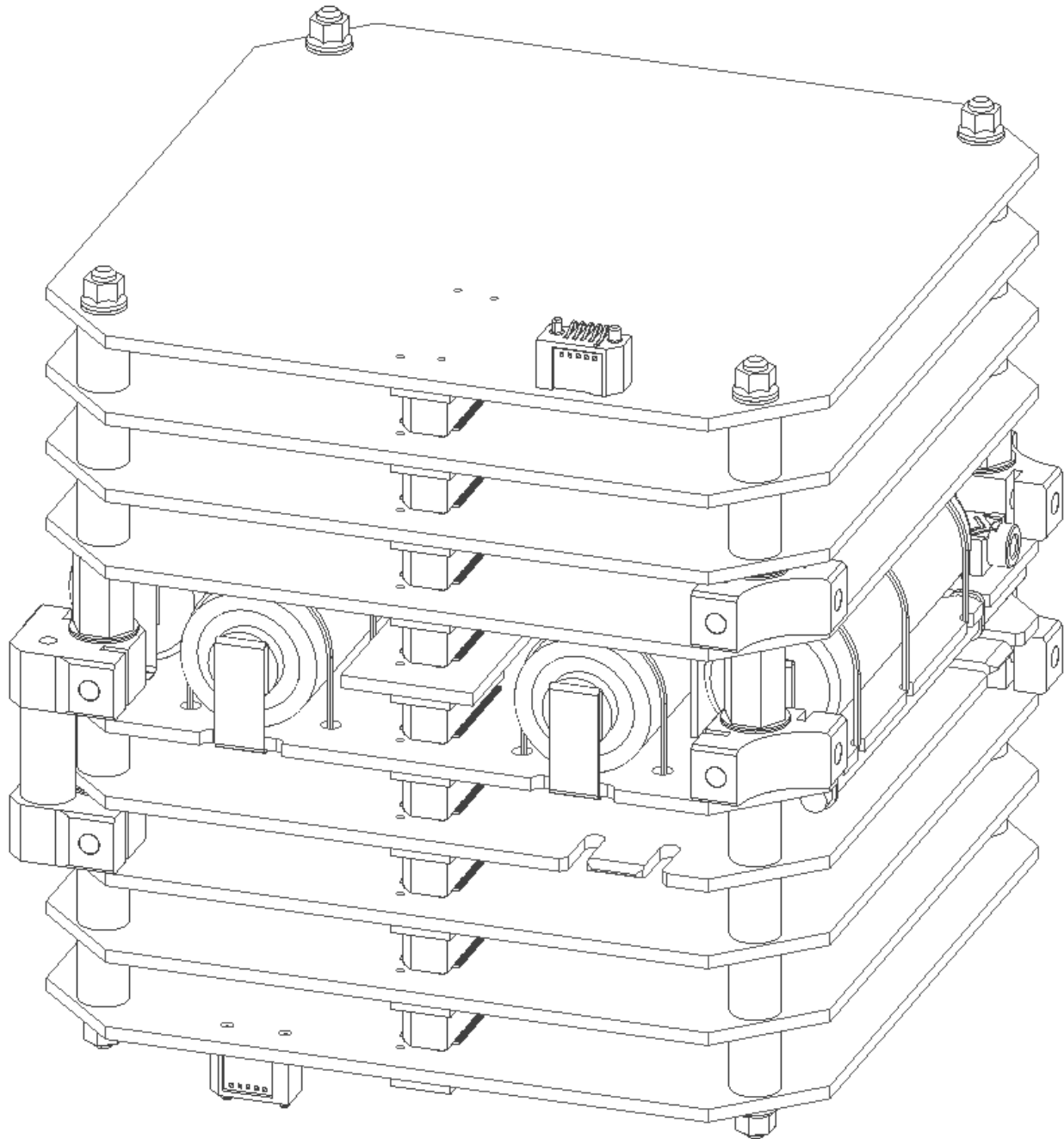


Figure 7 PCB Stack of Avionics and Experiments

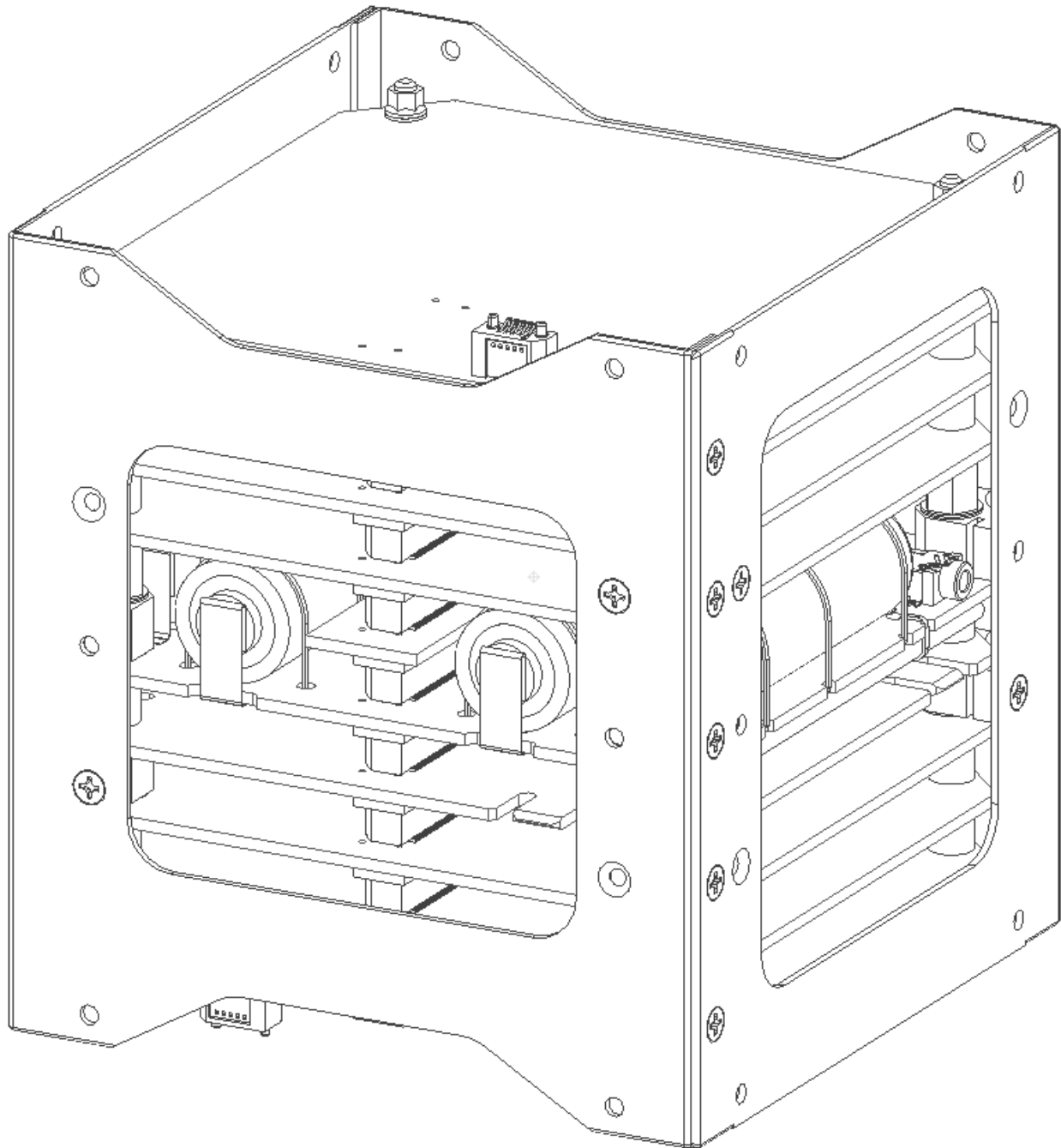


Figure 8 PCB Stack slides into Walls

Solar Panels

The six sides of the cube will be covered with fixed, Cell-Interconnect-Coverglass (CIC) solar cells. The side solar panels will be 82 mm wide and 108 mm long and the top and bottom solar panels just under 100x100 mm. The solar panel substrates will be standard thickness (.062 inch) PCBs.

The +X and -X Solar Panels have access holes for 2.5mm audio jack and mini-USB, which are visible thru the access holes provided by the P-POD.

The +Y and -Y Solar Panels stow the whip antennas.

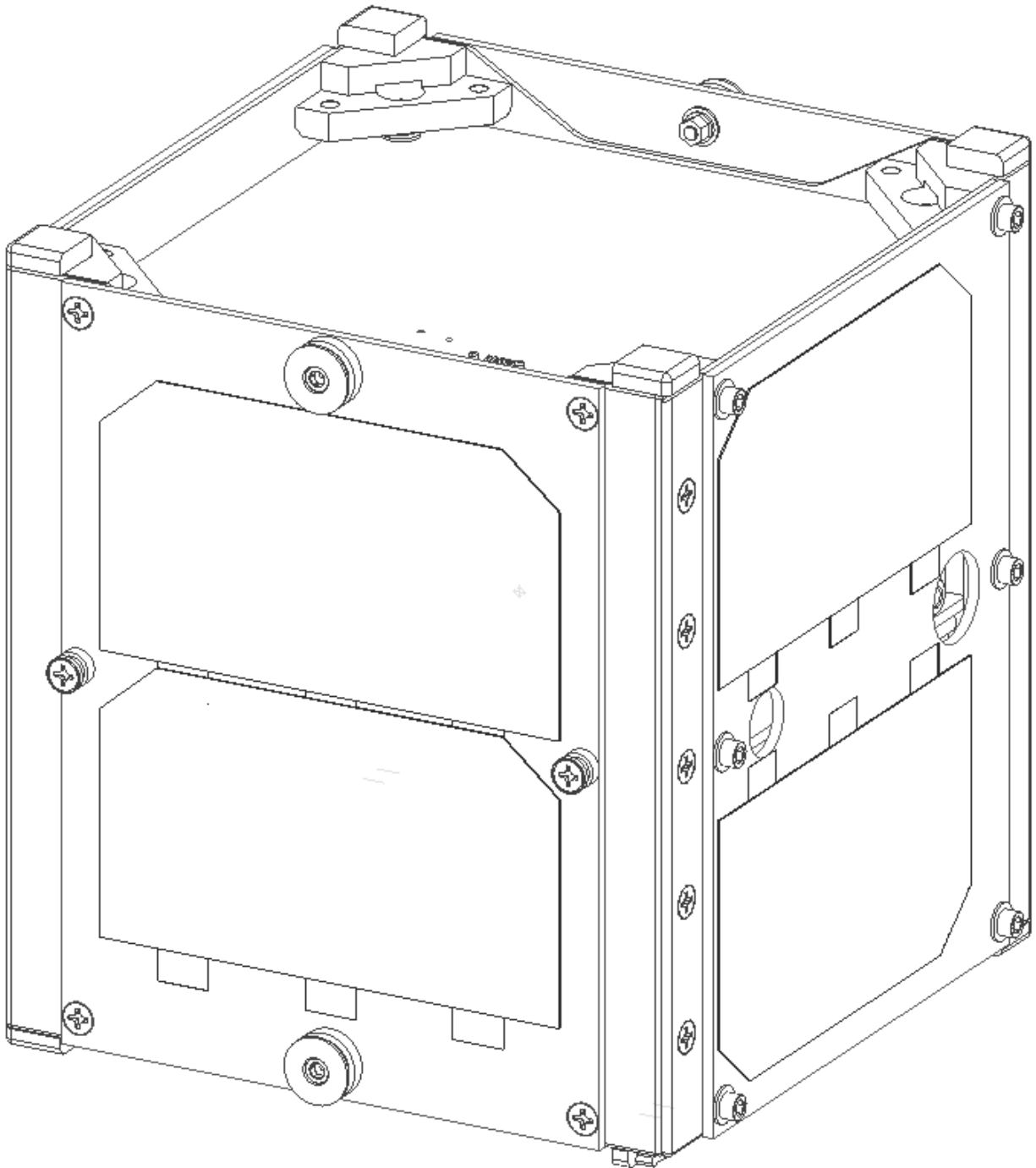


Figure 9 Install Side Solar Panels and Rail Ends

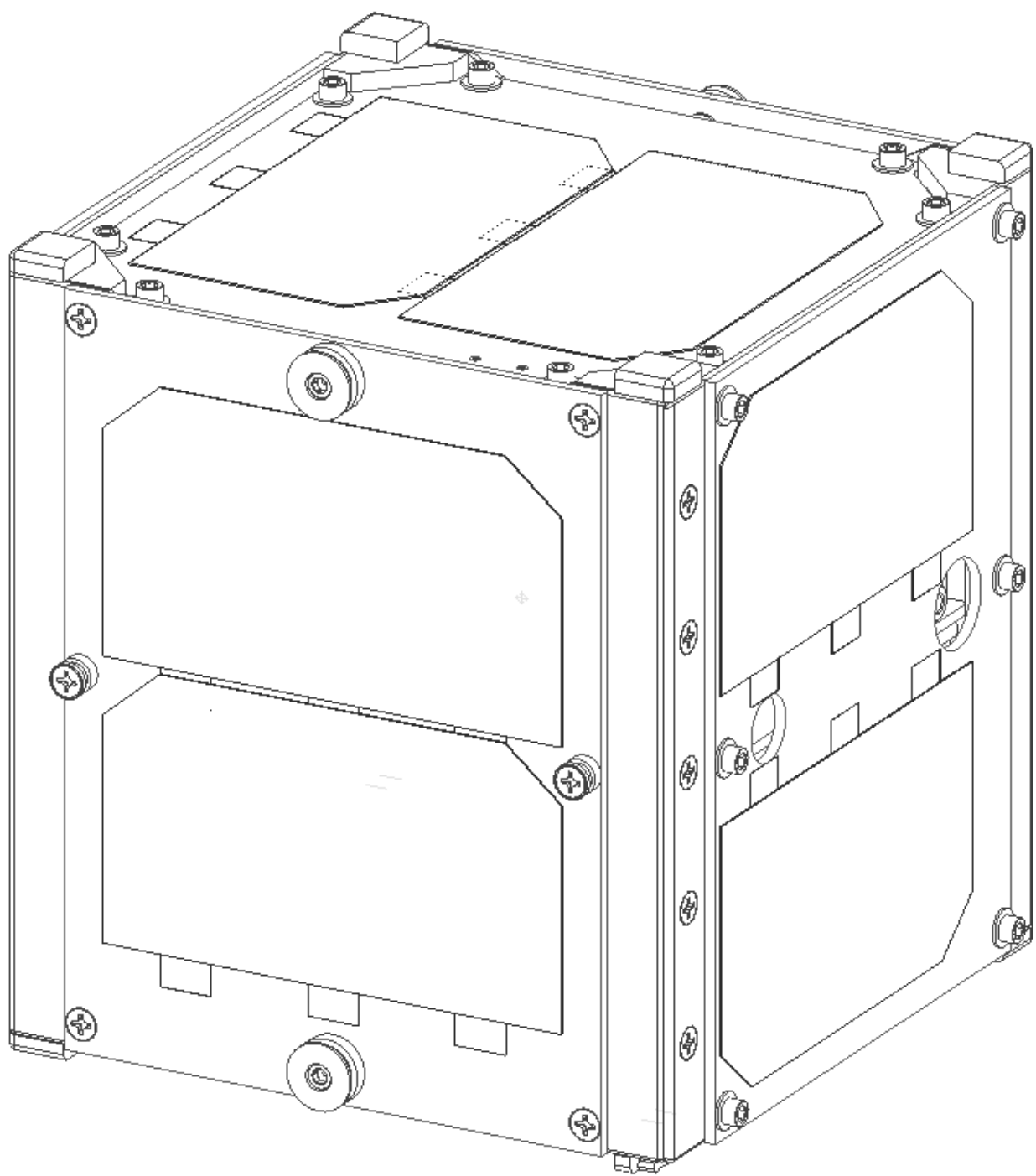


Figure 10 Install Top and Bottom Solar Panels

Antennas

The whip antennas were originally planned to wrap around the entire cubesat, and emanate from the Top & Bottom Solar Panels. Difficulties in a simple "sharp bend" around the edges of the cubesat, and concern about vibration alignment, drove a different solution.

The whip antennas are now wrapped around posts above the +Y and -Y solar panels. See Figure 1. This allows the bend radius to be larger than could have been afforded going around the edges of the cubesat, without reverting to torsion springs. The posts have a small groove to hold the wire above the panel. Two of the posts are aluminum and allow us to check electrical continuity for status of antenna stowage. The wires are stowed in their oval shapes by fishing line tied to the ends. The fishing line will be melted using a high temperature resistor.

Engineering Unit

All parts will be prototyped before the flight units are built. At the Symposium this year, we expect to have most parts, if not all, prototyped.

Fox-1 Thermal Design - Update

Presented by

Dick Jansson, KD1K

Abstract

The very dramatic reduction on the size of electronics and their concurrent increase in complexity and capability are making possible multi-function satellites in very small volumes. The CubeSat program was born as this complex electronic environment was birthing. CubeSat is a small, 10cm cube 1/12 the volume of the previous “small” AMSAT Microsat program of 1990. Owing to the small size and mass it has become financially possible to launch these satellites on small budgets. AMSAT is now in the process of exploring this field and size of satellites as finding launches for our previous designs has become nearly impossible.

While the size of these satellites has been reduced, the complexity of the thermal design and the supporting analyses has not really diminished at all. This paper will document the thermal design and analyses of the AMSAT Fox-1 program. This paper is an update of the one presented last year at the Space Symposium.

About the Author

Dick Jansson, KD1K (ex: WD4FAB, WA1QLI), holds AMSAT and ARRL life memberships. He resides in Winter Park, Florida.

Dick has been participating in the thermal and mechanical designs of AMSAT satellites since 1978 starting with the late lamented Phase 3A; then to Phase 3B – AO-10; and to Phase 3C – AO-13. He conducted a study effort in the Geosynchronous Phase 4 effort before working feverishly on the 27 month Microsat Program culminating in 1990 with the quad launch of AO-16, DO-17, LO-18, and WO-19. Attention was almost immediately then turned to the ten year Phase 3D program resulting in the AO-40 satellite. In 2000 a study period commenced for a follow on in the Eagle study program which was subsequently abandoned. Other recent efforts have been dealing with ARISSat and now the CubeSat, Fox-1.

1 Introduction

A CubeSat is a type of miniaturized satellite for space research that usually has a volume of one liter, standardized as a nominal 10x10x10cm cube, weighs no more than 1.33 kilograms, and typically uses commercial off-the-shelf (COTS) electronics components. Beginning as the brainchild of Prof. Bob Twiggs, KE6QMD, AMSAT member, of Stanford University in 1999 and promulgated in conjunction with California Polytechnic State University (Cal Poly) the CubeSat specification was developed to help universities worldwide to perform space science and exploration.

The term "CubeSat" was coined to denote nano-satellites that adhere to the standards described in the CubeSat design specification. Cal Poly published the standard in an effort led by aerospace engineering professor Jordi Puig-Suari. The specification does not apply to other cube-like nano-satellites such as the NASA "MEPSI" nano-satellite, which is slightly larger than a CubeSat. AMSAT has evolved its own initial specification based on the Cal Poly document.¹ This AMSAT document is ITAR controlled and is not a generic CubeSat document.

With their relatively small size, CubeSats could each be made and launched for a 2013 estimated cost of under \$100,000 to LEO for a 1U model. This price tag, far lower than most satellite launches, has made CubeSat a viable option for schools and universities across the world. Because of this, a large number of universities and some companies and government organizations around the world are developing CubeSats — between 40 and 50 universities were developing CubeSats in 2004, Cal Poly reported.

This paper will examine the thermal environment of a CubeSat and its thermal design to insure workable temperatures for the spacecraft electronics.

2 Mechanical Arrangement

From a thermal standpoint the only part of the AMSAT specification that is of thermal design interest is that of the operating temperature: -40°C to +50°C. While this seems a bit stringent, one of the goals of this thermal design effort is to provide more suitable "arm-chair" conditions for the installed equipment in Fox-1.

The Fox-1 external mechanical arrangements are shown in Figure 1. This structure is covered on all six sides with solar panels, each composed of two large UTJ solar cells of $\approx 28\%$ efficiency. The operational electronics Printed Circuit Boards [PCB] are arranged in a stack, Figure 2 that is located in the central portion of the spaceframe, Figure 3, providing a centralized placement for the battery mass. This arrangement is to comply with the requirements that the Center Of Mass [COM] is within 2cm of the geometric center of the allocated volume for the spacecraft.

Panels on the sides of a CubeSat are allowed to protrude up to 6.3mm in certain proscribed areas of each side. The outer 8.5mm of each side of the spaceframe is reserved for a **Rail**, running in the Z direction, reserved for the launch system, with proscribed finish and aluminum oxide coating. The AMSAT design sets aside 9.5mm for each rail. That, then, allows for an 81x108mm PCB-based solar panels on the X and Y sides and a nominal 100x100mm solar panel PCB on the Z sides. These Z-side dimensions seemingly imply space left over on the Z panels but there are other functions that must be ac-

commodated in that space, such as the separation switch, separation pads and their push-off springs, and U and V band antennas. With all of these functions using spacecraft external area, there is just no room left over for any kind of thermal control surfaces. Essentially the entire spacecraft surface is spoken for and with materials with preset radiative properties. We may be able to sneak some solar-absorbing gold plating on spare areas of the solar panels.

While it appears that there is room left over on the solar panel PCB, the high-efficiency triple-junction solar cells shown are the largest practical at 68.9x39.5mm. Manufacturer's catalogs show some larger cells that would more adequately fill this PCB area, but those cells are not really a standard product and would be very costly to purchase and implement in this design.

3 Heat Sources

By far the single most profound heat source for a spacecraft is the Sun, providing a 6000K radiant heat source of from a distance of 149Mkm (1 AU). As such it provides heating in the visible and near infrared spectrum, 0.3 μ m to (about) 4 μ m. The response of materials to this radiant source is measured in terms of their non-dimensional Solar Absorptance, α_s , property. The α_s is in deference to a material's radiation response to radiation in the far infrared, in the range of 4.0 μ m to 25 μ m, called the Emittance, or ϵ_{IR} , property. Compounding the solar heating issue is the fact that there are a range of values of the solar "constant", going from a "cool" sun, at 0.13081W/cm², to a "warm" sun, at 0.13995W/cm². A nominal value of solar heating of 0.13660W/cm² is often used.

A second heat source to a spacecraft is that of the reflected solar radiation from the illuminated side of the earth, called Albedo with maximum values ranging from 0.05516W/cm² to 0.03530W/cm². Spacecraft surfaces respond to lower heating values of albedo radiation in the same manner as to solar radiation. Albedo radiation is a property that must not be ignored as it can be very useful to a spacecraft. Albedo radiation is an orbital geometric heating property that depends where a spacecraft is located over the solar illuminated side of the earth and the orbital altitude.

The third radiant heat source for a satellite, especially for those in Low Earth Orbit, or LEO, is that of the planetary far infrared emission. The earth is a heat source of approximately 290K providing far infrared heating values of 0.01891W/cm² to 0.02616W/cm². The amount of this radiant source is pretty much a constant value for a satellite in circular orbit but is a changing value for satellites in elliptical orbit owing to the pure geometry of how much of the 4 π steradian, sr, of the solid spherical angle of space sphere around a satellite is filled by the earth. For satellites in High Elliptical Orbit, HEO, the planetary emission heating value is generally so small that is ignored.

The fourth heat source for a satellite is that of internal dissipation of the electronics; see **Table 1** for the cold case and **Table 2** for the hot case. This depends upon how much of the incident solar, and albedo radiation is converted to electrical power then consumed (dissipated), by the electronics and thence converted to heat. In many satellites the electrical dissipation is often considered a nuisance but in Fox-1 it turns out to be a beneficial property. The battery dissipation is that of specific thermostatically controlled heaters on the cells to keep them warm enough to be able to accept charging.

Table 1 Cold Case, Tx Off, 33% Eclipse PCB Power Dissipations

PCB	Dissipation, W
Tx	0.164
Rx	0.067
IHU	0.090
PSU	0.010 - 0.043 (in sun)
Battery	0.010 – 0.210
Experiment	0.000
Total	0.341 – 0.574

Table 2 Hot Case, Tx On, Full Sun PCB Power Dissipations

PCB	Dissipation, W
Tx	0.290
Rx	0.067
IHU	0.090
PSU	0.370
Battery	0.010 – 0.210
Experiment	0.100
Total	0.927 – 1.127

4 Heat Sinks

To get rid of the heating caused by the above noted sources requires a heat sink. The ultimate heat sink for a satellite is that of radiation to the “cold black space” envelop surrounding the structure. In reality the space heat sink is not at absolute zero, but actually at about 4 Kelvin as a residual from the originating big bang. From a thermal standpoint of a satellite operating from 250 to 310 Kelvin there is not much difference in the space heat sink from 0 Kelvin, thus the 4 Kelvin is commonly ignored.

Internally in the Fox-1 spacecraft the effective heat sink (by conduction and radiation) for the electronics is the spaceframe. I shall not qualify this situation further until I get into the discussion of the thermal design as there are some things that are different in Fox-1 than I have seen in any of our prior AMSAT spacecraft.

5 Thermal Control Methods

All spacecraft temperatures are controlled by the nature of their external coatings. The values of absorptance, α_s , and emittance, ϵ_{IR} , are very important and are determined by careful measurement. Most materials have been so characterized and books have been written to document these properties. Prior to the advent of our interest in spaceflight, such documentation was generally not very well understood, available, or documented. Sixty years ago in colleges and universities the Heat Transfer courses generally only gave passing interest to the issues of radiant heat transfer. These days such oversight cannot be tolerated for aspiring satellite engineers.

In most spacecraft programs a significant effort is expended to insure that the coatings, both inside and outside the spacecraft, are well understood. In fact substantial control of the temperatures of a spacecraft can be achieved by such methods as the use of Multi-Layer Insulation, MLI; or solar absorbing coatings, generally metallic films; or solar re-

flecting coatings, such as second-surface mirrors of quartz or particular types of Teflon. Internally material coatings also play a part in the control of electronic box temperatures.

In the case of the Fox-1 spacecraft we do not have any liberties in adjusting the external coatings as the spaceframe size and features precludes any specific area for the use of thermal control materials save, perhaps, a small amount of gold plating on the solar panels. The eight 8.5x108mm rail surfaces must have a specified finish of aluminum oxide coating while the remainder of the area is spoken for by the solar cells and their PCB mounting boards. These surface properties are what they are and there is no latitude for any adjustments. This is a situation that I have not heretofore seen or had to work with as it places some rather serious restraints on the thermal design (sadly taking matters out of the hands of the designer).

As will be seen, the temperature variations of the spaceframe are substantial. Normally electronic modules or, in the case of Fox, just PCBs are mounted directly to the spaceframe. If that is done, as has been done in the past, the PCB temperature variations would also be substantial along with the spaceframe. These temperatures are somewhat in excess, both too warm and too cold, of what would be desirable for the electronics and so steps need to be taken to alleviate this situation if possible, as will be seen.

Other factors noted in dealing with the electronic PCBs is that we have electronic functions on a single small PCB that in the past required a whole sizable module to accomplish. In addition the power dissipation of the whole spacecraft is at the most a very few watts. To combat the spacecraft temperature variations, as reflected in the PCB temperatures, the mounting of the PCBs will provide a conductive coupling of the boards together as a stack as shown in Figure 2 and then provide as much thermal isolation of this stack from the spaceframe as possible, through the use of Delrin plastic mounting blocks, so that the limited power dissipation of this PCB stack can be used for self-heating to provide a more benign temperature environment for these electronics. This has been seen analytically and needs to be capitalized for the flight hardware. This whole process needs to be approached carefully. This process affects a number of factors, such as: PCB size; PCB stack assembly; PCB stack mounting to the spaceframe; and the PCB stack radiant heat transfer to the interior of the spaceframe.

Adverse factors affect how well this PCB stack is thermally isolated from the spaceframe. In addition to the overall thermal conductance of the Delrin mounting blocks, we will have sizable conductance of the electrical connections between the solar panels and antenna to the PCB stack. While numerically these conductance values look small, their influence is profound. For example, the following **Table 3** values have been estimated and used in this modeling:

Table 3 PCB Stack to Spaceframe Thermal Conductance Values

Element	Conductance, W/°C
Delrin Mounting Blocks	0.009435
±X Solar Panel Connectors	0.00330
±Y Solar Panel Connectors	0.00551
±Z Solar Panel Connectors	0.00342
Tx & Rx Coaxial Cables	<u>0.00330</u>
Total Conductance	0.02496

6 Analytic Methods

The first steps of building, or composing, a thermal analytic model is to create a numeric geometric model for radiation analysis, both for internal spaceframe radiation and for the external orbital heating from the sun and earth. Creating the required numeric model calls for a close look at the mechanical design such as shown in Figures 1-3. For Fox-1 we see that it is composed of a collection of flat plates whose geometry can be numerically described and located in the relative spacecraft coordinate system. The spacecraft can then be geometrically located in the orbital coordinate system.

For this radiation analytic effort we employ a suite of Monte-Carlo ray tracing analysis software contained in a package called NEVADA. For the internal radiation evaluation RENO software (part of NEVADA) is used to report the radiant interchange factors while for the orbital heating of the solar radiation and earth emissions, VEGAS software is used. Both of these programs use the same, or similar, input files. Models can be assembled using somewhat expensive automated software, but we have felt that these steps are not needed. Most automated programs create rather large and highly detailed models that have much more complexity than is justified by the thermal needs of the structure. These programs provide output files that are used directly with the SINDA thermal analyzer, or with further text editing to create the needed files.

For the thermal analysis proper a different numeric model is created for use with the SINDA/G package. The spaceframe is composed of a description of the spacecraft surfaces as nodes with thermal conductors (either by thermal conduction or radiation) linking those nodes. Creating this type of model of a spacecraft greatly depends upon the experience of the analyst to insure that a meaningful model is assembled but one that is not so complex that it cannot be understood. Highly detailed models can be created but that added detail is of little value as there is, generally, little interest or value in knowing the temperature gradient across a surface. You can see that the KISS principle is at work here.

These software packages are not recommended for the uninitiated to use as I have found, even with many years (≈ 50) using them, which I have had to discover new features, capabilities and ways of doing things.

7 Data Handling

In the process of understanding the output data of this analytic effort, a series of Microsoft Excel spreadsheets (SS) were created. Such a tool has been shown to be needed to make sense of handling a large amount of output data. Despite the relative simplicity of the thermal analytic model there is a need to be able to clearly understand these results and to portray the results in a manner that allows the engineer to understand how model variations affect the end results.

This effort evolved further with an expansion of the SS that incorporated the input files for VEGAS and SINDA as well as their output files. This SS tool has helped us understand and document the analytic work flow and the overall analytic effort immensely. The expanded SS have also greatly helped by reducing the amount of manual labor in the extensive text editing needed in certain areas of the thermal analytic effort, as well as

incorporating the very useful graphical presentations of output data. The SS effort has also made possible an understanding of how satellite motions can be modeled in the desired tumble motions and to properly code those into the VEGAS input file.

8 Analytic Results

The available spreadsheet results are usefully expressed in several charts to illustrate the Fox-1 temperatures and incident and solar cell generated power levels. Other papers will be used to discuss the power results as that subject will require some close attention to illustrate those issues. This paper will only discuss the satellite thermal performance and the resulting temperatures. This task is not as simple as it may seem as we have run analyses for many situations of orbital orientation, “warm sun and “cool sun” heating values and satellite orientation. This has resulted in quite a few models that were used to examine the boundaries of spacecraft operation. Providing just a couple of snapshot view of this data in this paper does not reflect all of the work done.

A further consideration is the modeling of electronic power dissipations of PCBs that have yet to be designed. These dissipations can then be considered as educated targets for the thermal model and the electronic designers both. The target for the average spacecraft power dissipation is to not exceed the minimum power generation of about 2.1W. For that this thermal model used the dissipation numbers of Tables 1 & 2 for the PCBs.

Early on in this effort it was realized that nominally connecting the PCBs to the spaceframe could bring some extreme, and undesirable, temperatures to the electronics. This resulted in assembling, in the thermal model, a conductive stack assembly of the PCBs and a minimum conductance to the spaceframe which has been a challenge for the spacecraft mechanical designer. This consequently resulted in a moderation of the PCB temperatures. These results are shown in Figures 4 Spacecraft Temperatures, 5 PCB Temperatures, and 6 Solar Powers, for the 33% maximum eclipse orbit, with minimum solar radiance (cool Sun), illustrating that PCB self heated temperatures ranged from about -11.3°C to -4.7°C with the battery thermostatically controlled between +7°C to +8°C. These temperatures are a bit cool but workable for the electronics.

Warmer results are seen in Figures 7 Spacecraft Temperatures, 8 PCB Temperatures, and 9 Solar Powers, for a full-sun orbit, with maximum solar radiance (hot Sun), showing the PCB stack running from +5.0°C to +6.7°C with the battery operating at +7.4°C again thermostatically controlled.

9 Future Work

The analytic results shown to date have promise for being able to offer a modest temperature environment for the spacecraft electronics. Along the way, a very capable set of analytic tools have been created to speed up the process of creating these analyses. It is clear that more work is needed before creating flight hardware. The added work needed will be discussed below.

Another issue that needs attention is that of the PCB dissipations. We have used one nominal set of estimated power values that may not be like the final values. Clearly the

spacecraft must be able to operate within the boundaries of the available power generation. Having the high efficiency UTJ solar cells has made CubeSats possible in the first place, but that power is still highly limited and must be employed wisely.

The Fox-1 program so far has been aimed toward the Fox-1 mission, with a relatively simple set of electronics and with no deployable solar panels. For the future, however, we will be aiming for Fox-2 with its increased complexity and capability. Fox-2 may need to have deployable solar panels so as to provide the added power for the electronic payload.

One issue that has not been addressed is the variable power consumption than may be needed for different parts of an orbit as in eclipse. Other ultra-low-power operations need to be defined and quantified.

Another modeling variable is that not all of the solar power may be needed for the whole orbit, yet our current models unrealistically uses all of the power all the time that it is available. This modeling issue was addressed more than twenty years ago in the Microsat program. This FORTRAN code, which is still available, removed the rated generated power from the solar panels, operated the necessary equipment and charged the battery until its rated energy is stored and then, with less than full power needed from the panels, lowered the power removed from the solar panels, effectively adding heat to those panels. Battery stored energy was removed as needed during eclipse. This code dynamically models the complete energy balance of the satellite.

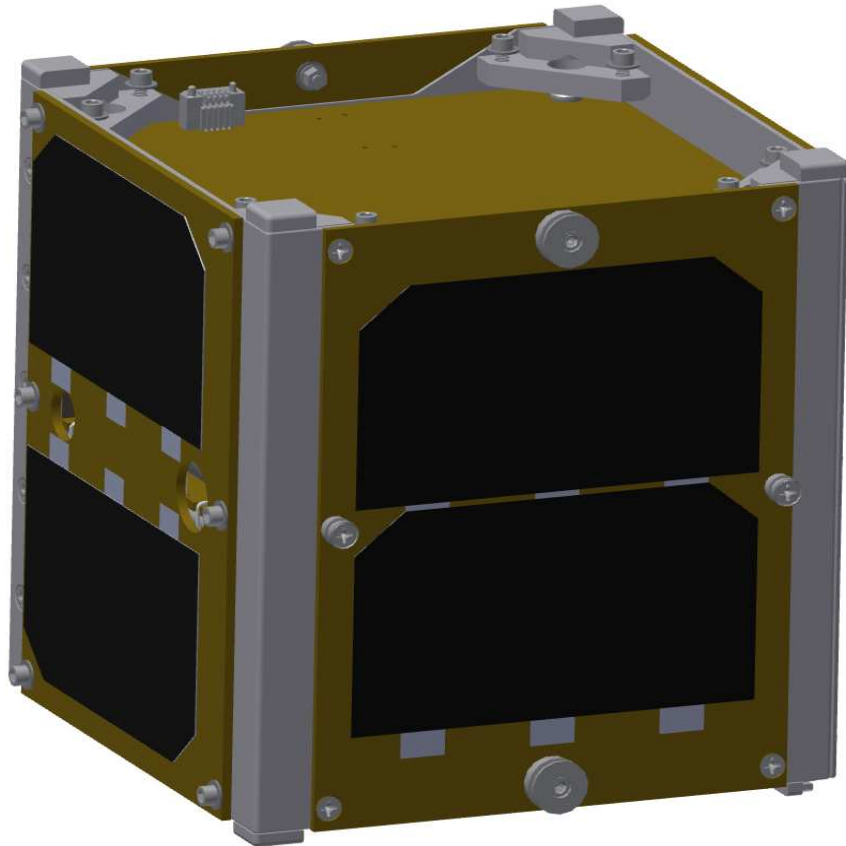


Figure 1 Fox-1 spaceframe assembly.

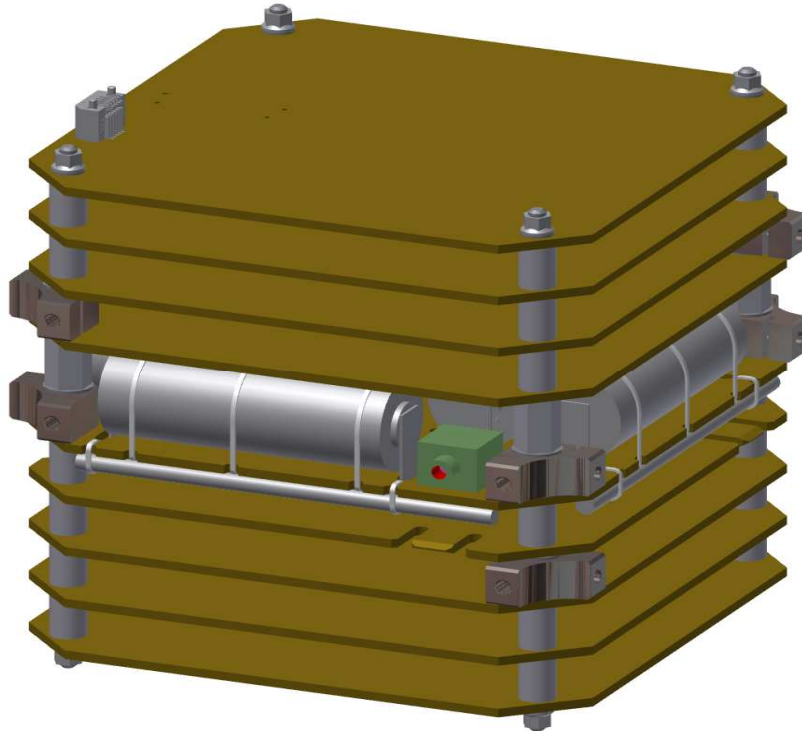


Figure 2 Fox-1 PCB Stack showing the battery cells in the center.

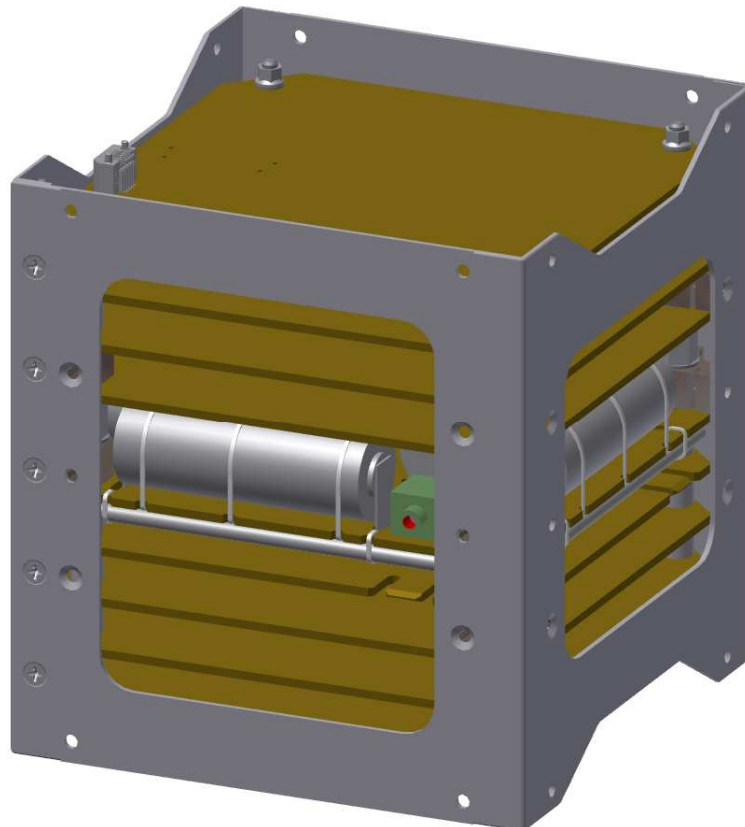


Figure 3 Fox-1 bare spaceframe with centrally mounted PCB stack.

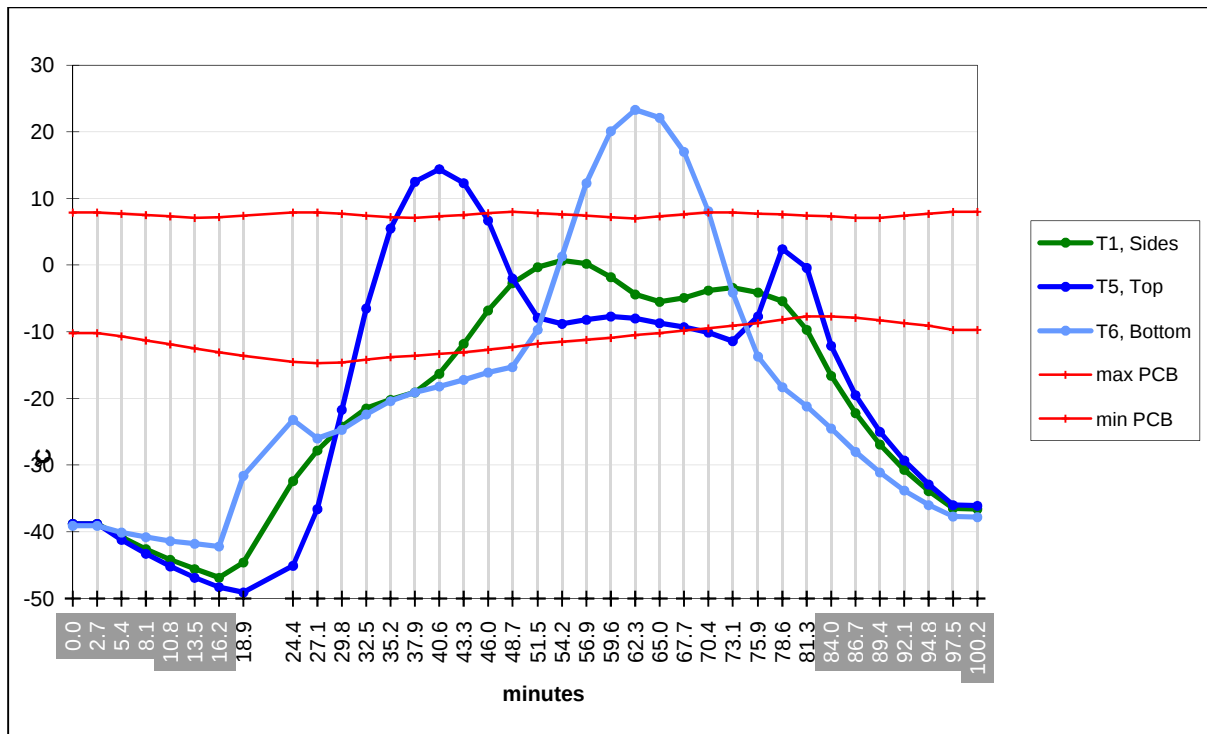


Figure 4 Fox-1 temperatures for 33% eclipse orbit with thermally isolated electronics.

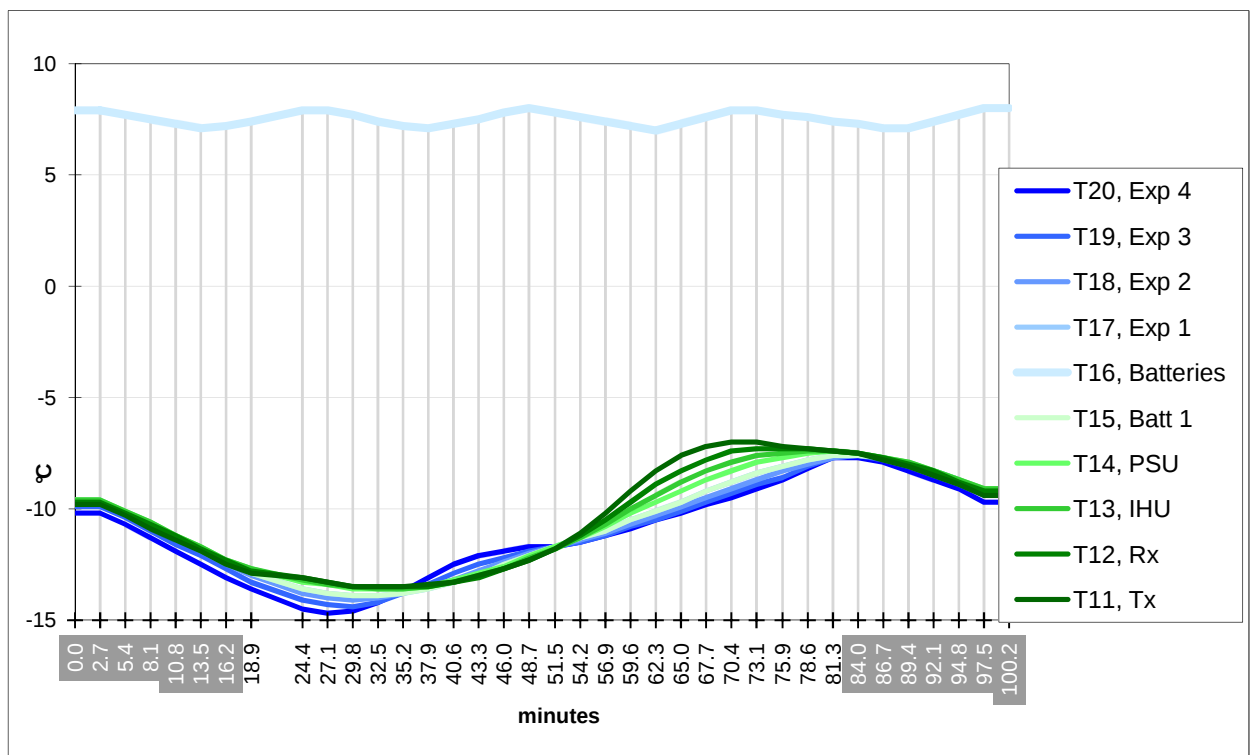


Figure 5 Fox-1 PCB temperatures for 33% eclipse orbit.

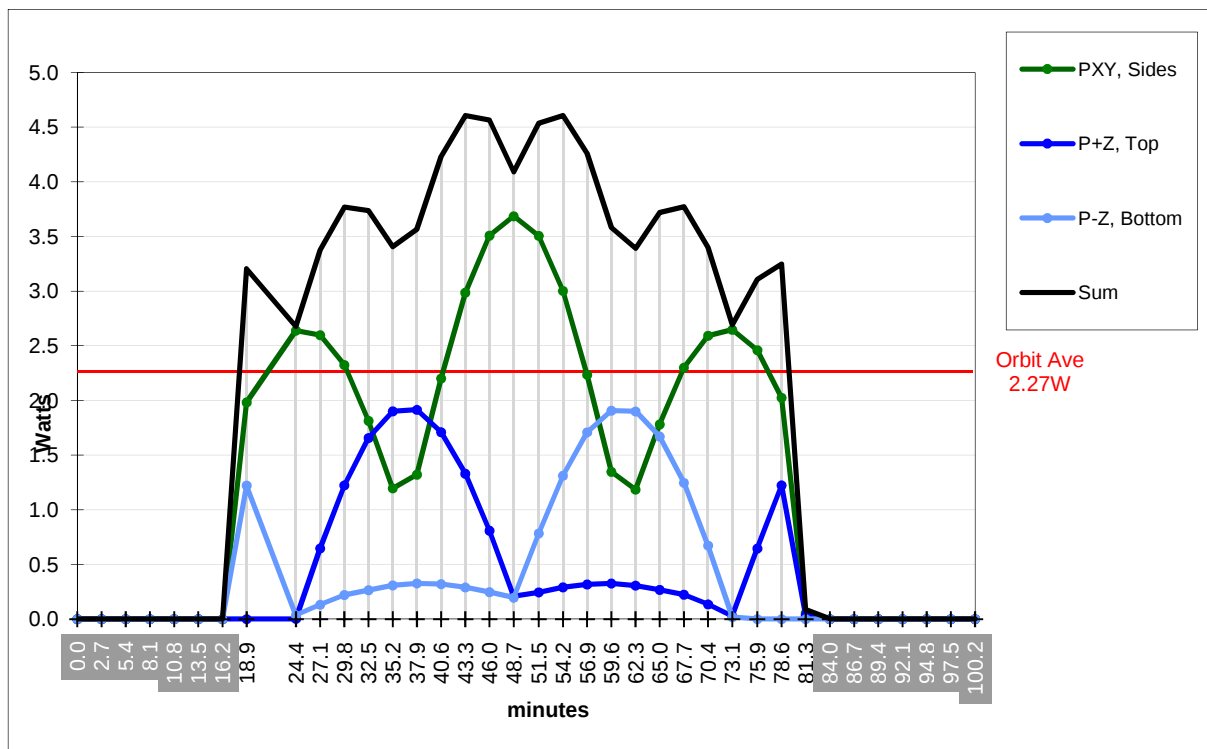


Figure 6 Fox-1 solar power generation by different panels for 33% eclipse orbit.

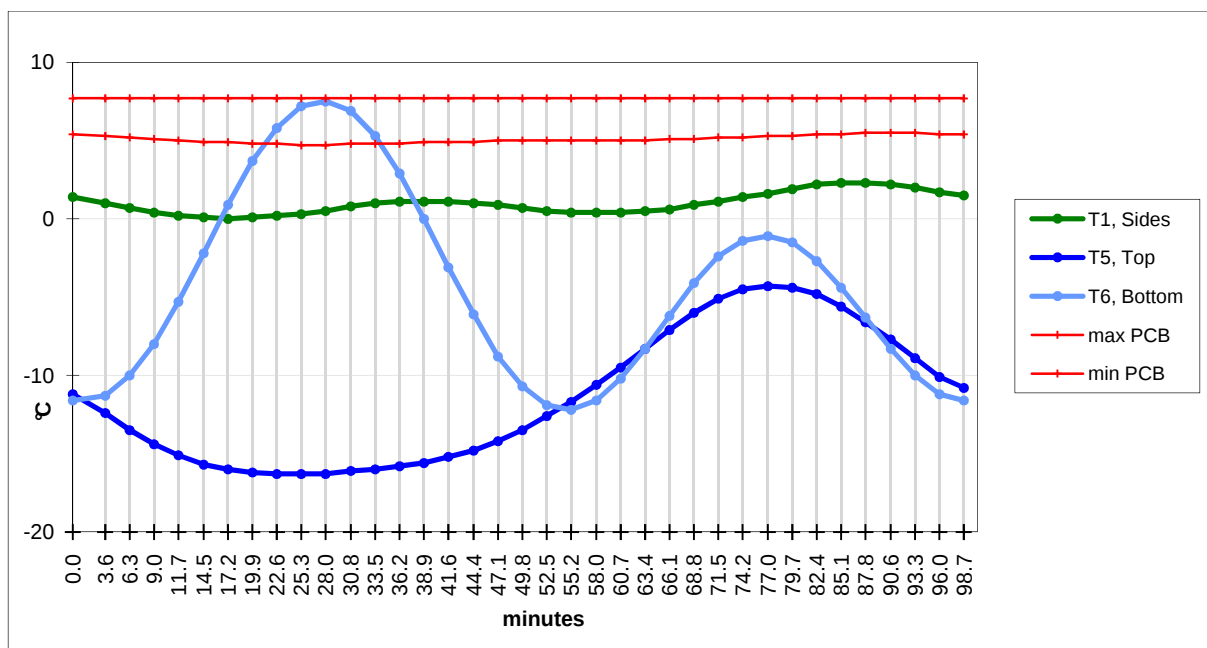


Fig 7 Fox-1 temperatures for full-sun orbit with thermally isolated electronics.

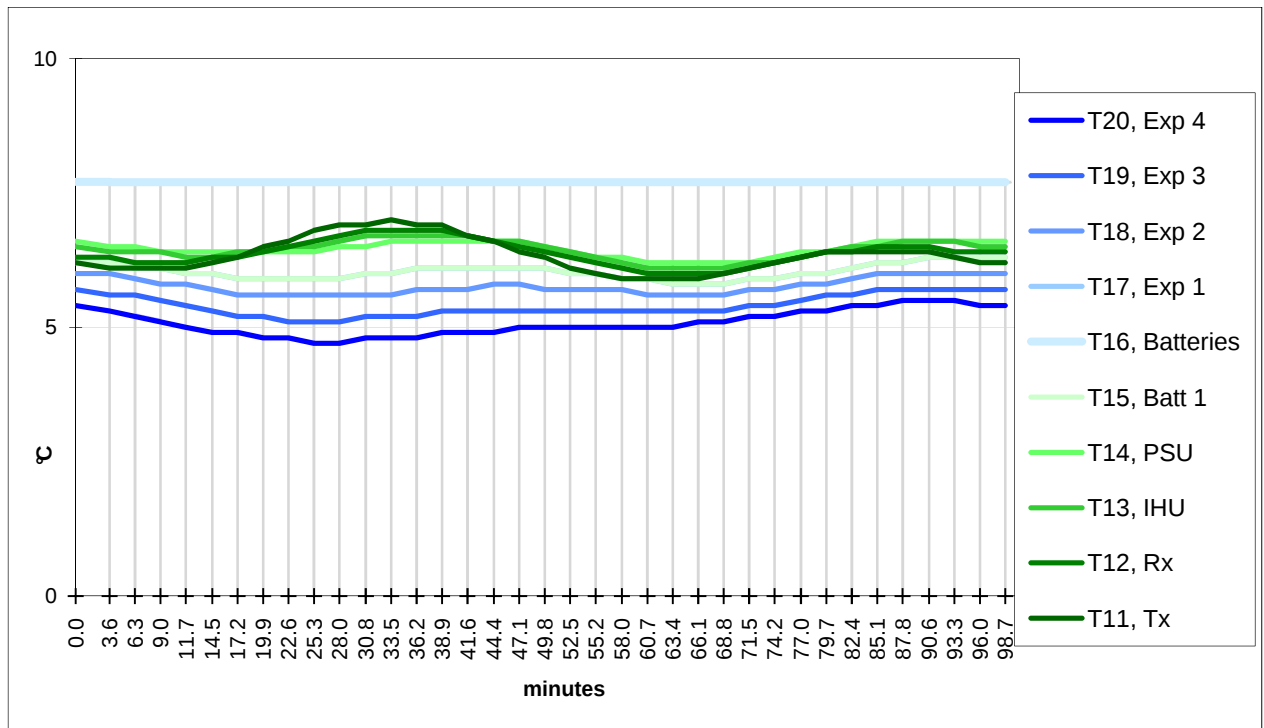


Figure 8 Fox-1 PCB Temperatures for full-sun orbit.

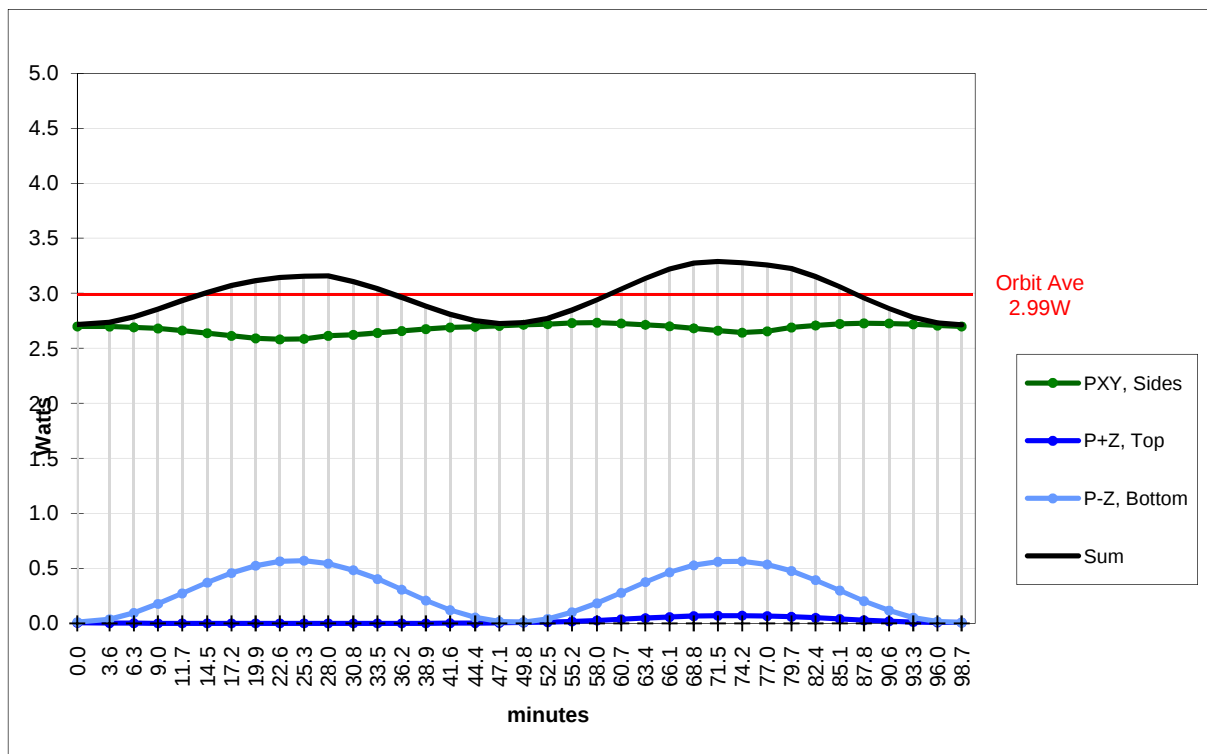


Figure 9 Fox-1 Solar power generation for full-sun orbit.

FoxTLM - A Software Demodulator and Telemetry Display Program for the Fox-1 Satellite

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Abstract

FoxTLM is a complete software DSP demodulator and telemetry display program for the telemetry from the Fox-1 satellite.

Introduction

FoxTLM is a graphical Windows program for displaying telemetry from the Fox-1 satellite. The program is written in C and compiles with Qt, which uses the GNU Compiler Collection (gcc) for compilation. FoxTLM is freely available under the terms of the GNU Public License (GPL). The author hopes to use the experience and lessons learned from creating the ARISSatTLM telemetry program while designing and building FoxTLM, while also trying to avoid Brookes's second system effect. [1]

FoxTLM, like ARISSatTLM, will be able to demodulate the telemetry from the satellite without the need for a TNC or an external modem. The demodulation will be done using digital signal processing techniques. ARISSatTLM used a soundcard to digitize the audio coming from a radio receiver. FoxTLM will also be able to use a soundcard to digitize the audio from a receiver. In addition, it is expected that FoxTLM will be able to use an I and Q data stream from a software defined receiver. This part of the software is still under development, but the I/Q stream could come from a FUNcube dongle [2] or perhaps even over a network connection from some other type of software defined receiver.

The Fox-1 satellite telemetry will be unique among amateur satellites with FM voice downlinks. The telemetry will be transmitted at the same time as the FM voice downlink using the audio range usually reserved for sub-audible tones such as Continuous Tone-Coded Squelch System (CTCSS). It is expected that the telemetry will be sent continuously as long as the transponder is on or once every five minutes along with the CW identification. The telemetry will run at a slow speed, perhaps one hundred bits per second, and include forward error correction (FEC). The FEC will allow the telemetry ground stations to detect *and correct* errors in the received telemetry. Without FEC every single bit in the telemetry must be received correctly in order to have a valid telemetry frame. With FEC added, some of the bits can be received incorrectly, and they will be corrected in software.

Fox-1 Telemetry Frames

Successfully demodulated telemetry frames will have the telemetry values extracted. FoxTLM can then interpret those values and display the decoded telemetry values for the user. These frames are also saved to a .CSV file on the local hard drive. The file will be named YYYY-MM-DD.CSV, where YYYY is the year, MM (or M) is the month, and DD (or D) is the date. Each frame is saved to the file by appending the file if the file already exists. This ensures that no received telemetry is accidentally overwritten. The frames are written to the file with one line per frame. Each frame starts with the date YYYY/MM/DD, a hyphen, the time (UTC) as HH:MM:SS; then each (raw) byte of the demodulated frame is written as a decimal value. For example, a telemetry frame line might start as

```
2012/12/31-23:59:59,072,105,044,116,104,105,115,032,105,115,032,  
070,111,120,045,049 ...
```

The .CSV file can then be imported into any number of common spreadsheet programs for further

analysis.

In addition, the FoxTLM software can forward the successfully demodulated telemetry frames over the Internet to a telemetry server. The telemetry server will receive all of the telemetry frames from all of the ground stations and use the latest telemetry to update a webpage. The author expects to have separate webpages with the decoded telemetry formatted to display properly on smaller screens (for mobile users) as well as on larger desktop/laptop screens.

Fox-1 Telemetry Frame format (*Preliminary*)

The formats of the telemetry frames are still subject to changes. Some of the fields in the telemetry frame are a direct result of experience gained from the telemetry from ARISSat-1. In particular, it is planned that the Fox-1 telemetry frame will contain a reset counter. The actual count will be stored in non-volatile RAM. When the count is combined with an incrementing telemetry frame number, this will allow each telemetry frame to be unique even in the absence of a timestamp.

Field	Size (Bytes)	Type	Value	Description
Frame Header	1	Fixed	ASCII 'T'	Identifies this frame as a spacecraft telemetry frame
Fox ID	1	Fixed	0x01	0x01 specifies Fox-1. 0x02 is reserved for Fox-2.
Telemetry Version	1	Fixed	0x01	Telemetry Frame format version number. This number must be incremented if the format changes.
RTC Timestamp	4	Unsigned Integer	Variable	RTC timestamp (time must be UTC)
IHU Reset Counter	4	Unsigned Integer	Variable	Count of the number of IHU resets from non-volatile FRAM
Frame Counter	4	Unsigned Integer	Variable	Count of the number of slow speed telemetry frames sent since the last IHU reset.
CELL 1 V	2	Unsigned integer	Variable	Battery cell 1 voltage raw value
CELL 2 V	2	Unsigned integer	Variable	Battery cell 2 voltage raw value
CELL 3 V	2	Unsigned integer	Variable	Battery cell 3 voltage raw value
CELL 4 V	2	Unsigned integer	Variable	Battery cell 4 voltage raw value
CELL 5 V	2	Unsigned integer	Variable	Battery cell 5 voltage raw value
CELL 6 V	2	Unsigned integer	Variable	Battery cell 6 voltage raw value
CELL T	2	Unsigned integer	Variable	Battery temperature raw value
TOTAL I	2	Unsigned integer	Variable	Total system DC current raw value
+X PANEL V	2	Unsigned integer	Variable	+X solar panel voltage raw value
-X PANEL V	2	Unsigned integer	Variable	-X solar panel voltage raw value
+Y PANEL V	2	Unsigned integer	Variable	+Y solar panel voltage raw value
-Y PANEL V	2	Unsigned	Variable	-Y solar panel voltage raw value

		integer		
+Z PANEL V	2	Unsigned integer	Variable	+Z solar panel voltage raw value
-Z PANEL V	2	Unsigned integer	Variable	-Z solar panel voltage raw value
+X PANEL T	2	Unsigned integer	Variable	+X solar panel temperature raw value
-X PANEL T	2	Unsigned integer	Variable	-X solar panel temperature raw value
+Y PANEL T	2	Unsigned integer	Variable	+Y solar panel temperature raw value
-Y PANEL T	2	Unsigned integer	Variable	-Y solar panel temperature raw value
+Z PANEL T	2	Unsigned integer	Variable	+Z solar panel temperature raw value
- Z PANEL T	2	Unsigned integer	Variable	-Z solar panel temperature raw value
SPIN	2	Unsigned integer	Variable	Calculated spin rate
Serial Number	4	Unsigned integer	Variable	Identifier based on a serial number to identify the telemetry based on the specific source hardware
Signature	4	Unsigned integer	Variable	Signature of the telemetry frame plus the IHU serial number (used to validate that this telemetry really came from the satellite)

Source Code Availability

For those who are interested in the FoxTLM source code, it will be available on a software repository under the terms of the GNU Public license (GPL). Currently, the FoxTLM software can be compiled with Qt version 4.2.4 under Windows.

Fox-1 Telemetry for Everyone

In addition to the Windows version of FoxTLM, there will be a version of FoxTLM for Apple computers. The Mac version is being developed independently by Gilbert Mackall. Similar to the way that ARISSatTLM was written, it seems likely that both the PC and Mac programs will use the exact same DSP routines for demodulating the audio signal into the telemetry frames, and on-the-air demodulator performance is expected to be identical.

Since the Windows version is written in Qt, it is likely that a Linux version can be compiled from the same (or very similar) Qt source code. If you are interested in the Linux version, then the author would like to hear from you regarding some specifics such as your preferred Linux distribution.

Those with mobile devices are not going to be left out either. There are plans for a web page on the www.foxtlm.org website (or on an AMSAT website) which will contain a copy of the most recently received telemetry. After Fox-1 is in orbit, any ground station which receives telemetry from the satellite can forward the telemetry to the Internet telemetry server which will update the telemetry webpage. Based on experience with ARISSat-1, the telemetry web pages will probably be updated every minute or two whenever the satellite is in view of a telemetry ground station. In addition, there are plans for a leaderboard page with statistics showing which ground stations have contributed telemetry and how many telemetry frames they have submitted. The author is hopeful that this will encourage competition among

the ground stations and ultimately result in more telemetry being collected.

Education and Experimentation

As a part of the signup process during the installation of the FoxTLM software, the software will ask the users for their location. Using their location and current two line orbital elements (TLEs), the time of the next satellite pass can be computed. However, the reverse calculation should also be possible and might be a good student exercise for an advanced class. Given enough telemetry frames, the times when the frames were received and the location of the ground station, it might be possible to calculate the orbital elements [4]. It might also be possible to have the ground stations measure the frequency of the received signal from the satellite, including the observed Doppler shift, and then calculate the orbit from those measurements and station positions.

Food For Thought: Do you know anybody at McMurdo Station?

In an attempt to collect as much telemetry as possible, from as many locations around the world as possible, it would be desirable to have ground stations around the world. Before ARISSat-1 deorbited, telemetry was sent in from around the world from hundreds of telemetry ground stations.[5] However, even with all of these telemetry ground stations, there were still times when the satellite's orbit placed it out of range of all of them. Fox-1 is scheduled to be placed into an approximately ninety minute polar orbit which will travel over the north and south poles. A telemetry ground station in Alaska or one located at McMurdo Station would see the satellite pass overhead on more of the orbits than a telemetry ground station in the continental United States. A telemetry ground station in Hawaii would also be desirable to add coverage over the Pacific Ocean. One idea still under development is a stand-alone automated unattended telemetry ground station using a combination of a small computer such as the twenty-five dollar Raspberry Pi with a simple receiver such as a FUNcube dongle or a DVB receiver dongle. The Raspberry Pi is a credit card sized ARM11 based computer running Linux. [6] Among other peripherals, it includes two USB ports and an Ethernet port. There is also a Raspberry Pi Linux distribution optimized for running Qt applications. [8]

Even in remote areas where the transponder is not activated by the users, the satellite will send a CW ID and a telemetry packet about every five minutes. The prospective telemetry ground station would need to supply power and an Internet connection, but the telemetry from remote locations will probably only amount to a few thousand bytes (yes, *bytes*) of data per hour. An antenna is also desirable. Interested parties are encouraged to contact the author.

Conclusion

Comments and criticisms on FoxTLM and the source code are welcome as well as bug reports and bug fixes and suggestions for features and enhancements. [7]

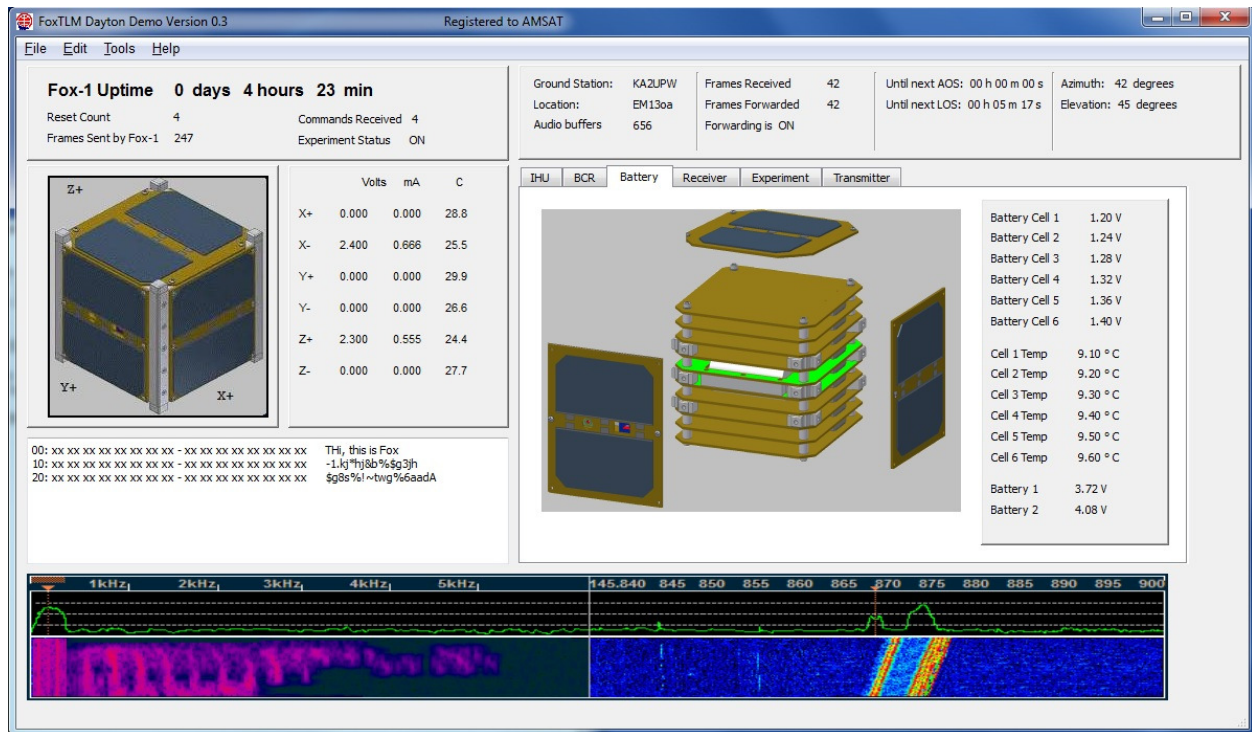


Figure 1 - Screenshot from FoxTLM main window (Windows Version)

References

- [1] Brooks, F. P. The Mythical Man-Month, Essays on Software Engineering. Crawfordsville, Indiana: Addison-Wesley, 1995.
- [2] The FUNcube dongle is a software defined radio in a package the size of a USB thumb drive. See <<http://www.funcubedongle.com>>.
- [3] [deleted]
- [4] This also assumes a reasonably stable orbit, which, unfortunately, ARISSat-1 didn't have.
- [5] Quagliana, Douglas D. "Decoding Satellite Telemetry from ARISSat-1." Proceedings of the AMSAT-NA 29th Space Symposium. 2011.
- [6] See the Raspberry Pi Frequently Asked Questions at <<http://www.raspberrypi.org/faqs>>
- [7] The author encourages constructive criticisms and particularly welcomes deconstructive comments and puns, and perhaps any suggestions and remedies you might have for excessive "and" conjunctionitis.
- [8] QtonPi. See <<http://www.raspberrypi.org/downloads>>
- [9] The Hitchhiker's Guide to the Galaxy. Cambridge: InfoCom, 1984.
- [10] 'Isn't it fun reading through the footnotes?' [9]

Installing The FOX-1 Build Environment on Linux

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AMSAT Space Symposium 2012

The Fox-1 Amateur Radio Satellite will use an ST Micro STM32L151 processor for the IHU (internal housekeeping unit). Initially, the software development team is using an STM32L1xx Discovery evaluation board. This board can be powered, loaded, and debugged over a USB connection to a host computer. The board is available from Digikey or Mouser for under \$15.

This paper describes how to install an Eclipse-based ARM toolchain on a Linux host computer. While several of us have used this particular toolchain with the Discovery board, we anticipate that the identical toolchain will work with the Fox-1 IHU board.

I have done this work on a native Linux system, although a bit of checking on a Virtual Box virtual machine shows that it “mostly” works. The only difficulty is in connecting the Discovery board to the virtual machine via the USB port.

Although I try to describe nearly every step in some detail, I do assume that you can deal with Linux, even if you are not an expert, and that you can search for common procedures on the web. For example, the first step is “Install Ubuntu 12.04” without a lot of additional detail.

You also need to be aware that if you follow the descriptions below, you will generally be fetching the latest version of open source software from its distribution site. That means that it is subject to change. Not that a changed version will necessarily fail to work; more likely it will have additional or fewer dependencies or there will be slight differences from the procedures that I describe here. You need to be flexible. This procedure works as of about 1-Sep-2012.

INSTALLATION SUMMARY

Here is the general idea of what you will be doing. More details come later.

1. Install Ubuntu 12.04
2. Install git
3. Build the summon-arm toolchain
4. Install the Eclipse IDE for C.
5. Install the GNU ARM plugin onto Eclipse.
6. Install the C/C++ GDB Remote Debug plugin into Eclipse
7. Install the egit Eclipse plugin
8. Install a gdbserver (the Texane STLink gdbserver on native Linux)
9. Clone the example git repository
10. Create the debug configuration

SYSTEM SPECIFICATIONS

I used the Ubuntu 12.04 64-bit distro as the OS base. This is a “CTS” version, which means it will be supported for quite a while. I’ve also built the toolchain on 11.10 and 10.04, both 32-bit and 64-bit but you might as well use the latest and greatest. The 64-bit version seems MUCH faster than the 32-bit version, but note that it sometimes talks about AMD in conjunction with 64-bits. The 64-bit Ubuntu version works with Intel as well...don’t worry. The instructions below all use the ‘apt-get’ command (used on Debian and Ubuntu etc.) rather than the ‘yum’ command (which would be for Fedora and Red Hat etc.). Certainly the procedures I describe could be done on Debian. I assume it could be on other distros; however the required downloads might be different and that’s the hardest part about doing all this without help. For that reason I suggest using Ubuntu.

I assume that you are in an account that has ‘sudo’ privileges...that is the default for the account you create when you install Ubuntu.

I have used a different font, Courier--like this, for things that should be typed. For menu items to select or buttons to push, I try to list the menu, tabs, and buttons with a slash between them. For example File/print would be selecting the print option on the file menu.

And finally if you are on a virtual machine with Virtual Box, at least during this build phase, be sure to set it up with a **bridged** network adaptor, not NAT. (NAT is recommended by the Virtual Box installation and is the default. Bridged access just uses more addresses from your router/DHCP server...no big worry). If you don’t do this, some ftp copies will hang.

INSTALL UBUNTU 12.04 (Precise Pangolin) Linux (Takes at least 30 minutes; probably more)

I find it easiest just to download the iso for a boot CD and burn and then boot the CD. Ubuntu 12.04 is the default, so it should be easy to find, but to save you that work, here is the URL for the download page: <http://releases.ubuntu.com/precise/> You can pretty much choose all the defaults on installing. Once you have installed (either natively, or in a virtual machine), login, create a terminal by entering ctrl-alt-T and then do the following procedures:

INSTALL GIT (Takes less than 1 minute)

```
$ sudo apt-get install git
```

(In all cases using sudo you may have to enter your password depending on how recently you have used sudo before)

BUILD SUMMON-ARM TOOLCHAIN (Takes about 15 minutes)

The tools you are building here consist of a C compiler/linker, a gdb debugger, and many other “standard” tools, as well as a clib. They are all “cross-tools”: they execute on a Linux/X64 system, but generate (or debug) code for an ARM Cortex M3 system.

First install some prerequisites for building summon arm. Note: prerequisites have changed across versions and time; there may be some things here that are NOT required with the latest versions.

These must all be typed without an “enter”. Alternatively, you can hit ‘enter’ anywhere there is a space between packages, but start the next line with ‘sudo apt-get install’.

```
$ sudo apt-get install flex bison libgmp3-dev libmpfr-dev libncurses5-  
dev libmpc-dev autoconf texinfo build-essential libftdi-dev libexpat1  
libexpat1-dev zlib-de* zlib-bin libtool ia32-libs
```

\$ sudo apt-get build-dep gcc-4.5 (This was required at one point, but may not be needed now. I have forgotten it occasionally, and recently that has not caused any problems. I include it because I have not done any careful checking and it does not hurt)

Now build the toolchain itself.

```
$ cd    Go to your home directory
```

```
$ git clone git://github.com/esden/summon-arm-toolchain
```

```
$ cd summon-arm-toolchain
```

```
$ git checkout remotes/origin/dev
```

```
$ ./summon-arm-toolchain SUDO=sudo PREFIX="/usr"  DEFAULT_TO_CORTEX_M3=1
```

This is a lot to type, but it should go perfectly smoothly if you do everything. I’ve repeated it many times on fresh virtual or physical machines. After it is done, check in /usr/bin to see if there are files called arm-none-eabi-xxx (where xxx is gcc, gdb, and many others). Note that the “git checkout” line is something new that is required in the last few months. I think there was a change that broke something so you have to get the latest development stream. In other words, that will probably change.

Note that it takes considerably longer to build on a virtual machine. You might check to be triple sure that you have the guest addons installed...that should speed things up somewhat. At some point, especially if you are on a slow machine, you may have to type in your password (for sudo) again, so keep an eye out.

INSTALL ECLIPSE (takes maybe 5 minutes)

```
sudo apt-get install java
```

In your browser go to www.eclipse.org and push the “Get Started Download” button. Then choose “Eclipse IDE for C/C++ Developers” 64-bit version (assuming you installed Ubuntu 64-bit, which I recommend)

It will ask you what to do with the download, and you can say to open in the archive manager. When it all opens, say “Extract” and you should get a directory called “eclipse” in your home directory.

Open eclipse as follows:

```
cd ~/eclipse
```

```
./eclipse
```

Eclipse should start up, and it should say “JUNO” on the splash screen. Eventually, it will prompt you for your workspace. I took the default and clicked “Don’t ask every time”. Explore the welcome screen if you wish, then close the welcome screen by clicking the X on the welcome tab.

If you are clever with Linux, you can move the entire eclipse directory anywhere you want and make an icon or something to access it easily. It also works fine if you just run it from your local directory.

INSTALL THE GNU ARM PLUGIN FOR ECLIPSE (5 or 10 minutes)

Go to the Help menu/Install New Software.

Click ADD (Note: some of these sites may already be there. If so, just be sure the check box is clicked. Some may be there, but say Indigo rather than Juno for the folder. Change it using ‘edit’.)

Enter “Juno Update Site” for the name, and <http://download.eclipse.org/releases/juno>

OK

Click ADD again and repeat for “CDT Juno” <http://download.eclipse.org/tools/cdt/releases/juno>

OK

If there are any sites listed which have “indigo” in them, edit them and change it to Juno. I think this is likely a bug in the release.

Click ADD again and repeat for “GNU ARM Plugin” <http://gnuarmeclipse.sourceforge.net/updates>.

Click OK.

Now use the pulldown and select the “GNU ARM” URL that you typed in a few minutes ago. In a few seconds you should see CDT tools appear below (probably only one)

Select ‘CDT GNU Cross Development Tools’. Click Next.

Click Next. Accept the license. Click Finish. You may have to say OK to unsigned content.

Allow eclipse to restart

INSTALL C/C++ GDB HARDWARE DEBUGGING (5 minutes)

Go to Help->Install New Software

In “Work With” enter <http://download.eclipse.org/tools/cdt/releases/juno> (you should be able to choose it from a menu since you entered it above)

In a few seconds you should get a window with “CDT Main Features” “CDT Optional Features” and a few others. Click the triangle beside CDT Optional Features to open the list below it, and then click in the box beside “C/C++ GDB Hardware Debugging”

Then click the finish button. It will ask about licenses and eventually restart Eclipse or ask you to restart it as above.

INSTALL EGIT PLUGIN (5 minutes)

As above, Help->Install New Software.

In “Work With” type <http://download.eclipse.org/egit/updates>

Click the triangle beside “Eclipse Team Provider” and choose “Eclipse Egit” (others seem tantalizing, but are not required, it would seem)

As above, it downloads and may restart Eclipse.

INSTALL THE TEXANE ST-LINK UTILITY ON YOUR NATIVE LINUX MACHINE (5 minutes)

Install the libusb package:

```
sudo apt-get install libusb-1.0
```

 (on an older Ubuntu it has a slightly different name.
Try libusb-1* and look at the list it gives you.)

Now build the st-link software

```
cd
git clone git://github.com/texane/stlink.git
cd stlink
./autogen.sh
./configure
make
```

It will be done in a flash.

Now do the following (to tell Linux how to recognize the Discovery card when it is plugged into the USB port):

```
sudo cp 49-stlinkv2.rules /etc/udev/rules.d

udevadm control --reload-rules
```

 (Note the spelling: control <space> <two dashes>reload<one dash>rules

Now plug in the Discovery card and type `./st-util`

Voila! It will listen on port 4242 for a connection from gdb/eclipse.

CLONE THE GIT REPOSITORY

Now we want to actually create a project in Eclipse that is a clone of a project in a git repository at a remote site. I have created an example project (which blinks the LEDs) in a github repository.

Before you actually do the following, please check my wiki on github:

<https://github.com/burnsfisher/amsat-example/wiki>

At the deadline for this paper, I was still working on the example; I will put any last minute changes on the wiki. But the following should be close to correct:

Start Eclipse

File/Import/Git/Projects From Git/Next

URI/Next

Now where it says URI type in the URL of the git repository:

```
git://github.com/burnsfisher/amsat-example
```

Now hit next.

At this point, you should get to choose the git branch. Currently the only one available is 'master'. After that it will give you several choices of what to do with the repository. You want to import a project from the git repository. Do **not** use the new project wizard! Import from a git repository is the equivalent of the git command 'clone'. It downloads quickly and you should have a project called "amsat-example" with the git embellishment beside it saying [amsat-example master].

The really good thing is that a lot of the metadata that gets Eclipse set up (build configurations, for example) is all part of the project you downloaded, so you don't have to do it so much yourself! You should be able to build the example now. You will have to set up a debug configuration to run it, though.

SETUP THE DEBUG CONFIGURATION

With Eclipse running, right click on the project and select "Debug As" and then "Debug Configurations". Create a new configuration based on GDB Hardware Debug. (Select GDB Hardware Debugging and press the little page-with-plus-icon). There are a couple places where it wants the executable .elf file. You may have to search for it, although sometimes it will default to the correct file. You should be able to give it a relative path name like Debug-Linux/FoxExample.elf or something like that. Next, go to the debugger tab and specify /usr/bin/arm-none-eabi-gdb as the gdb command. Also on the same page under "Remote Target", specify port number 4242 (to match the Texane stlink gdbserver above).

In the startup tab, you can add some gdb commands that will be executed after the code is downloaded and has stopped at the first instruction under 'initialization commands'. I suggest:

```
tbreak main
continue
```

This will set a temporary breakpoint at your main program, and then continue from the place where gdb initially stopped. That way it appears to you that the first thing that happens is that it stops at your main program. In fact it has executed some assembly language startup code that zeros memory and a few other things.

WHAT NEXT

This paper will not go into any detail about how to use Eclipse. There is plenty of help available on the web. Look at the reference in the next section, however. I'll just say that you can set up so that one of the Eclipse pushbuttons (External Tools) will start up the gdbserver, and that one easy way to start the debug configuration (and download the software into your Discovery) is to select the debug configuration and push the "Debug" button in the lower right. You can certainly experiment to find other ways as well.

One hint: Sometimes start up Eclipse with the command `./eclipse -clean`. Occasionally reality (which files have errors, where include files are located etc) gets out of sync with a cache in Eclipse. `-clean` forces a slower startup that rebuilds the caches.

What to do with it? The software in the git repository uses a very small amount of the STM "Standard Peripheral Library" V1.0.0. One thing that you could do as a first small project would be to upgrade this to the latest version from the STM website. Another, maybe even more interesting task, would be to find or design and write an open source library to access the STM32L1xx. I suggest that one goal would be to write a library that is licensed under the GPL (Gnu Public License, the 'standard' for open source code); another goal would be to write a library that required less memory and fewer data structures.

Another useful project would be to port the Texane gdbserver to Windows. As I mention below, I have not found an Open Source ST-link gdbserver available for Windows.

If you really enjoy working with this board and software, consider joining the AMSAT Fox software team!

FINAL COMMENTS

I have found this setup to work very well and quite reliably with everything running on the same Ubuntu Linux box. But notice that it is possible to have the Discovery board and the stlink/gdbserver running on one machine, while Eclipse and gdb are running on a different machine, and for them to talk over a LAN or an SSH tunnel. Unfortunately, I know of no open source, Windows-hosted gdbserver that can connect to the Discovery card via the stlink protocol. There is one from Atollic which comes with their free but crippled TrueStudio. While I have used this cross-architecture debugging it seems less robust, and has performance issues. Of course, since Eclipse is an X Window System application, you can have Eclipse running on one system and displaying on another. I have used an SSH tunnel to run the Linux system remotely while having the Discovery board and an X display on a local Windows system. Experiment!

Here are some general issues and questions that I know about right now:

- 1) It takes a very long time to download the program if you are sending it to the Atollic gdbserver on Windows...several minutes. It will look like it is hanging at 93% most of that time. If you are on a

native Linux box, the download via st-util is pretty quick (20 or 30 seconds maybe). This may be because of the packet size that the Windows gdbserver uses, but experimentation could be in order.

2) There is no button (as there is on the Atollic IDE) to reset and start the program from the beginning without reloading it. There is a debug command to reset, but I don't know how to connect it to the IDE. However, on Juno and with the Discovery board, pushing the "reset" button on the board seems to work fine, although the temporary breakpoint is not set in main.

3) On occasion, the program will not download. It just seems to hang. I have usually been able to get out of this situation by hitting the "stop" (red square) button. That sometimes causes the download to finish, but by then gdb is disconnected, so you have to do it again. On VERY rare occasions, I have had to unplug the Discovery card and plug it back in. You probably have to restart the gdbserver. At worst, stop Eclipse and the gdbserver, unplug and replug the Discovery card and restart gdbserver and Eclipse. I have never had to reboot Linux for this purpose. Someone else had a much harder time getting this to work. How he fixed it is still a mystery since it won't reproduce.

4) There are a few strange issues that I found a solution to by accident, and although I have fixed it twice, I'm not 100% sure if this is the answer. Several of us have gotten an error at the end of a build (it was a void dereference). The build had completed, and it would load fine, but we got an error dialog box at the end, so build-and-load in one step was not an option. The problem here appears to be in the build configuration section, where there is a tab for 'refresh resources'. It lets you specify what projects to refresh at the end of a build. If you have a closed project or non-existent project specified there, this problem happens.

REFERENCES

Here is a good reference that has some information about some of this build and setup (although it is aimed at Windows users):

<https://sites.google.com/site/stm32discovery/open-source-development-with-the-stm32-discovery/getting-hardware-debugging-working-with-eclipse-and-code-sourcery>

And yes, sourcery is spelled wrong at the end of the URL. Of course the product name 'Code Sourcery' is itself an intentional misspelling of 'sorcery'.

In addition, there is a lot of information about different possible parameters when you build the summon arm toolchain. You get a readme when you clone the repository, and there is also information on github:

<https://github.com/esden/summon-arm-toolchain>

ACKNOWLEDGMENTS

I would like to acknowledge and thank Bdale Garbee, KB0G, for the original impetus to try completely open source tools; Bdale and Keith Packard, KD7SQG, for pointing out the Summon ARM and Texane tools; and Keith for help with my first foray building the tools on Debian. I recognize that I have not yet used ALL of your suggestions.

Bill Reid, NX5R, created the original version of this document for Code Sourcery tools on Windows.

Add ISS Packet Operation to Your Satellite Activity

(Use Equipment Already in Your Shack ... or Acquire it for Cheap)

By JoAnne Maenpaa, K9JKM (k9jkm@amsat.org)

Abstract: This article is aimed toward introducing new Amateur Radio Satellite operators to ARISS packet operations using radio equipment that they may already own. This is intended to be a guide to repurposing their terrestrial equipment for a start on space activities using the strong and predictable downlink of the ISS.

Meeting STEM Goals Gets Amateur Radio Aboard the ISS

The Amateur Radio station aboard the International Space Station is known as the ARISS program – the Amateur Radio on the International Space Station. Many astronauts and cosmonauts have amateur radio licenses. Amateurs from the ISS partner countries, in the USA, Russia, Japan, Europe and Canada, have set up the ARISS program to foster amateur radio communications between the astronauts and cosmonauts who reside on the station and stations on the ground.

ARISS was the first amateur radio projects to gain access to the International Space Station as it helps NASA fulfill Science, Technology, Engineering, and Math (STEM) goals for education. ARISS is an international educational outreach program partnering the participating space agencies, NASA, Russian Space Agency, ESA, CNES, JAXA, and CSA, with the AMSAT, ARRL, and IARU organizations from participating countries.

ARISS offers an opportunity for students to experience the excitement of Amateur

Radio by talking directly with crewmembers on-board the International Space Station. Teachers, parents and communities see, first hand, how Amateur Radio and crew members on ISS can energize youngsters' interest in science, technology, and learning.

In the current launch environment Amateur Radio in space enthusiasts have discovered that has become nearly impossible to gain a free (or, even low-cost) launch opportunity simply so that a bunch of hams can talk with each other. We generally have to be ready to explain our added value to a launch to even get the ear of the people in charge. The ARISS amateur radio gear on the ISS provides added value in its STEM educational mission. The beneficial side effect for Amateur Radio operators is that the ARISS station remains available for general amateur radio usage when it is not engaged in educational contacts. Since the signal from the ISS is generally very strong this is where you can take advantage of trying your hand on the “easiest of the Easy Sats.”

Easiest of the “Easy Sats”

Where to Listen

Knowing where to listen and where to transmit are important first steps to getting started. The table below shows the most common ARISS Amateur Radio frequencies. There are a few additional “special modes” such as a 1269.500 MHz FM uplink that are rarely, if ever utilized. School contacts use the 145.800 MHz downlink with unpublished uplink frequencies used at the school site. The most commonly used ISS Amateur Radio frequencies are summarized in the table below.

Many hams spend a lot of time listening for ISS crew activity on the strong 145.800 MHz downlink. They often express disappointment that no FM voice activity had been heard for weeks. Crew activity depends a lot on their time available plus personal interest in making random contacts. Some prior crews made voice contacts frequently while use of the ARISS amateur radio gear is limited to school contacts for other crews.

Most Commonly Used ISS Amateur Radio Frequencies	
Mode V APRS (Worldwide APRS Digipeater)	
Uplink	145.8250 MHz FM 1200 BPS
Downlink	145.8250 MHz FM 1200 BPS
Mode U APRS (Worldwide APRS Digipeater)	
Uplink	437.5500 MHz FM 1200 BPS
Downlink	437.5500 MHz FM 1200 BPS
Mode V/V Crew Contact (Regions 2 & 3)	
Uplink	144.4900 MHz FM
Downlink	145.8000 MHz FM
Mode V/V Crew Contact (Region 1)	
Uplink	145.2000 MHz FM
Downlink	145.8000 MHz FM
Mode U/V (B) FM Voice Repeater (Worldwide)	
Uplink	437.8000 MHz FM
Downlink	145.8000 MHz FM
Mode V SSTV Imaging	
Downlink	145.8000 MHz FM

Packet is Where Its At (most often it seems)

Packet activity from the ISS is often noted on the **145.825 MHz** downlink. The uplink is on the same **145.825 MHz** frequency. Since the crew rarely engages in keyboard

contacts, most of the packet activity you are hearing is originated from earth stations using the ARISS digipeater. Lacking packet gear you will only hear the brzzzz-brap

sound of the 1200 baud audio frequency shift keyed (AFSK) signal.

You will need to know when the ISS is within range of your station. Refer to the appendix **Know When to Listen – Tracking Resources**.

Getting on the air with the ARISS packet digipeater can likely be accomplished with amateur radio gear you already own. No special amateur radio equipment beyond what is used for terrestrial contacts is needed to begin taking your first steps

toward Amateur Radio in space. This means if you do not own certain items they can likely be acquired inexpensively. Think of ARISS packet radio as regular ham radio (including packet) aimed skyward.

The good news is once you have equipped your station for ARISS packet and learned the ropes for ARISS operation your station will be ready for those rare voice contacts with the ISS crew. You will just need to switch the packet gear for a microphone and start calling.

Get Your Station Going on 145.825 MHz Packet

When packet radio was popular on VHF/UHF many years ago you may have acquired your Terminal Node Controller (TNC) which you interfaced to your FM radio. There were many packet bulletin board systems and personal packet mailboxes that were accessible via your TNC. That activity has diminished over time, having been replaced by the internet. You may have a TNC sitting on the shelf collecting dust. This same “old” hardware, capable of operating 1200 baud AX.25 AFSK modulation is still useful for packet radio operation via the ISS. There were many models of the AX.25 TNC including:

- MFJ-1270C TNC-2 Packet Controller
- Kantronics KPC-3 TNC

If you don't have a TNC that you used in the “old days”, these can often be purchased rather inexpensively at a hamfest. When you see a

good deal, grab it if you prefer the hardware approach to packet operation.

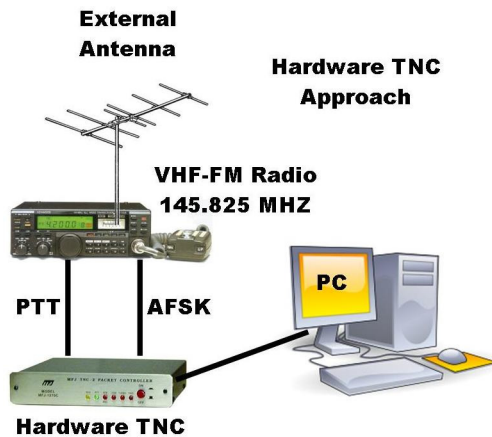
In the years since the peak of the hardware TNC based activity software for sending and receiving the AFSK packet signal has been created for the sound card in your personal computer. Your computer will perform the functions previously provided by a TNC hardware box.

In addition to the soundcard software you will need to install a soundcard interface between your radio and your computer to adapt the signal levels to be compatible with the digital signal processing done by the soundcard. You have a few options to this approach also.

- Build a soundcard interface from plans found on the internet.

- Rigblaster by West Mountain Radio \$100-\$300
(www.westmountainradio.com)
- Donner Digital Interfaces \$40-\$100
(www.donnerstore.org)

Whether you choose the hardware TNC or the software/soundcard TNC approach depends on what gear you have on-hand.

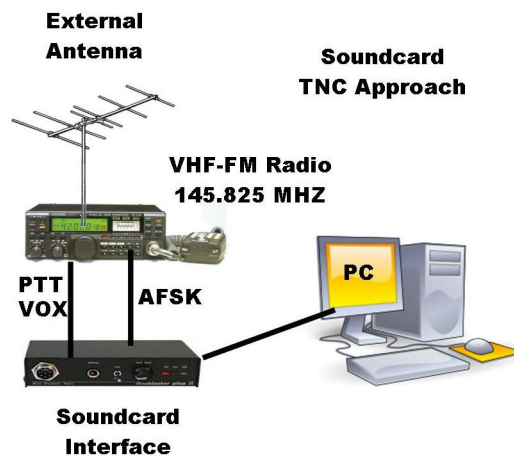


Overview of the Hardware TNC Approach

A hardware TNC requires a cable between it and your personal computer's RS-232 port. Many of the TNCs are sold with a cable that performs this function. Others come with a wiring diagram showing you which pins you need to connect. Additionally a cable is required between the TNC and your radio. If you previously had your TNC interfaced to your radio for terrestrial packet operation the connections remain the same for ISS packet operation. The personal computer needs to run a terminal emulator program so you can control the TNC, initiate messages, display received messages.

Overview of the Soundcard TNC Approach

The connection between your PC, the soundcard, and the soundcard interface consists of three separate connections in reality.



- You need to route the soundcard's LINE OUT connection to the interface. This will go to your TRANSMIT audio connection on the radio.
- You need to route the audio output from your receiver to the interface's received audio to the LINE IN connection on your soundcard.
- The serial port is used for push-to-talk rig control. Some stations have had success with using the VOX on the radio to key the rig during transmit. This is dependent on the type of radio you own (if this is available). Setting the sound drive levels may require careful adjustment so the radio reliably switches to transmit.

External Antenna is Recommended

The downlink signal from the ISS is very strong but you will not have much luck

trying to get your packets through the digipeater with an indoor antenna or with the flexible antenna on your HT. The good news is that your external antenna does not require full OSCAR-class tracking and control. Many enjoy success with a VHF vertical

antenna on the roof of the house. A small beam need not be complex. A 3-element VHF beam at a fixed elevation of 15-20 degrees on a small TV rotor is all that is necessary.

Overview of Operating Through ISS Using the TNC

Much of terrestrial packet operation consists of you requesting a CONNECTION to another station. Packet communication via ISS almost exclusively relies on using **CONNECTIONLESS** operation. The AX.25 protocol defines these types of packets as **UI packets**. An UI packet is pretty much transmitted out there for anyone and everyone to receive and copy. When stations transmit UI packets the AX.25 protocol will not be waiting for all of the handshake messages to complete – this very much simplifies the message exchanges. There are a few parameters in the TNC that make UI operation an easy mode to operate.

Every AX.25 packet that you transmit consists of two main parts: The Packet Header & Message Text. The Header contains your callsign which you set with the MYCALL command. Other packet stations will "know" it is a UI packet - a packet for everyone - based upon what you set in the UNPROTO command.

The most basic, barebones UNPROTO needed for ISS packet is simply set **UNPROTO CQ VIA ARISS**. You can add additional routing later as you become more familiar with packet operations. This

is all you need for your packet to get into space and be digipeated back to earth.

Assuming I have my UNPROTO defined as above, now all I need to do to transmit an UI packet from my station is to enter a short text message via the keyboard and terminal program on the PC. This requires the use of the TNC's **CONVERS** command as outlined here:

- Set UNPROTO CQ VIA ARISS.
- Enter CONVERS mode from the cmd: prompt on your TNC screen.
- Enter a short message such as *Greetings from JoAnne via the space station* and hit <enter>.
- You should see your TNC key your rig and send the message.

While you are in CONVERS mode all input from your keyboard is transmitted every time you hit the <enter> key. To exit the CONVERS mode at the end of a pass use Control-C (usually) to get back to the TNC **cmd:** prompt.

When the TNC-2 hardware is in a connection with a specific station node or in the CONVERSE mode it generally does not dis-

allow you to see all of what is going on the channel. Refer to the TNC-2 command table for details.

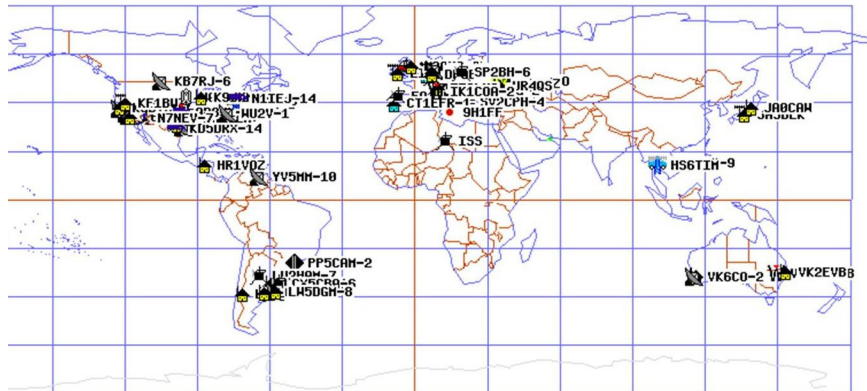
On The Air Example Using the TNC

The latest real-time ARISS packet activity is usually displayed on this web page:
<http://www.ariss.net/>

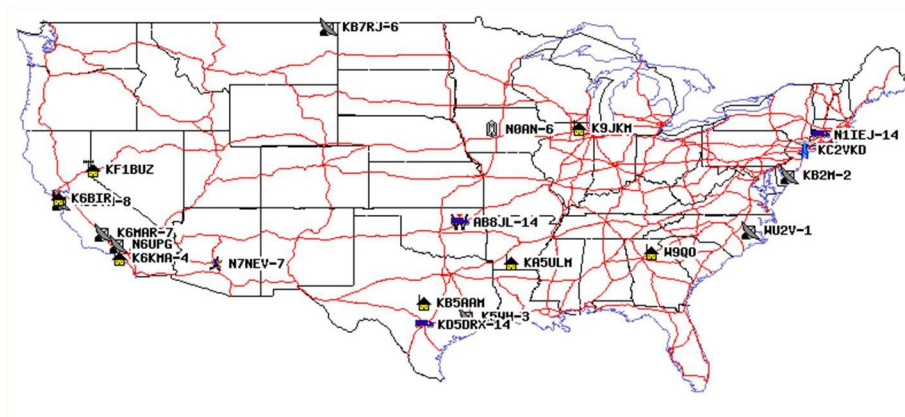
You will find a couple of nice features on this web page. You will see a real-time "heard" list of everyone who has had their

UI packets digipeated by the spacecraft. There is also a map display that will show the QTH of stations who provide APRS formatted location information. At the bottom of the pages you can view the entire packet of the most recent traffic from the spacecraft.

World Map Showing Stations Heard via ariss.net



USA Map Showing Stations Heard via ariss.net



APRS format location information?

No! You do not need to run any extra APRS software to be displayed on the map. You can generate the APRS format directly at your keyboard if you wish to show up on the map. If you wish to simply send text messages to be digipeated via the spacecraft you simply type your message without the location data. While your QTH isn't showing on the map your packets will in fact still be digipeated – and, that you will see on your screen.

Where do you find your APRS location information? This is just your GPS location. If you do not have access to a GPS box simply find your QTH on Google Earth (in the View -> Grid menu).

So if I would like to display K9JKM on the map and send a message to my fellow space-packeteers I should send a text string using the UNPROTO and CONVERS steps previously outlined, and make my message look like the example below:

=4211.29N/08827.08W-Hi from JoAnne near Chicago in EN52 <enter>

The parts of the message string can be explained as:

- **=4211.29N/08827.08W** is simply the = character plus my QTH info from Google Earth
- The – is the 'dash' or hyphen. It tells the map to display me as the little house with antenna icon. The ARISS packet page above has a link where you can find other icons for you on the map
- **Hi from JoAnne near Chicago in EN52 <enter>** can be any message text you wish. You will likely have better luck getting through and being digipeated if you transmit short messages.
- If I see someone on the downlink who I would like to have a keyboard QSO with all I would need to do simply enter the message from the keyboard without any APRS-formatted location: *Hi Bob, good to see you this pass* will just send Bob (and everyone reading the packet mail) your message.

The <http://www.ariss.net/> web page also shows a packet log of stations that have successfully digipeated. I highlighted one of my digipeats in the example below. I was digipeated by the RS0ISS-4* callsign (this is the callsign of the ARISS packet alias). The asterisk shows the last station to digipeat my packet. N6VUD-2 is running a SATGATE to transfer the packets to the internet and on to the web page.

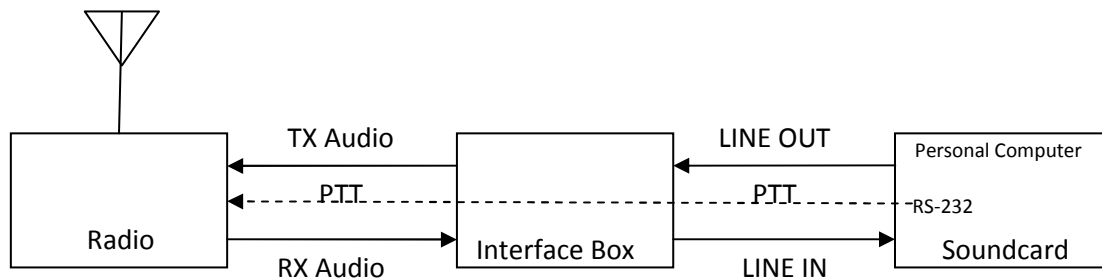
```
00:00:01:25 : K6KMA-4]APRS,RS0ISS-4*,qAr,GWS-2:=3349.51N/11806.91W-
00:00:01:35 : VA7VW-6]WA6YET,RS0ISS-4*,qAR,N6VUD-2:Hello from Ron in Vernon BC DO00ig
00:00:01:40 : K9JKM]CQ,RS0ISS-4*,qAR,N6VUD-2:=4211.29N/08827.08W-Greetings
00:00:01:45 : KD5DRX-14]TU4RUY,RS0ISS-4*,qAR,N6VUD-2:`1D2 {u/]"4;}Quinnesec Mi
00:00:01:45 : KB7RJ-9]TX5YXP,RS0ISS-4*,SGATE,WIDE2-2,qAR,N6VUD-2:`p]Ml!}k/]" ;m}146.520MHz QTH
Plentywood in NE MT=
00:00:01:51 : K6BIR]APU25N,RS0ISS-4*,qAR,N6VUD-2:=3739.56N/12206.43W- {UIV32N}
00:00:02:15 : VA7VW-6]K6KMA-4,RS0ISS-4*,qAR,K6SJC:Hello from Ron in Vernon BC DO00ig
```

Summary of the Hardware TNC-2 commands

The actual syntax to enter the commands into your TNC (from the **cmd:** prompt) will likely vary according to the manufacturer. The following list of parameters seems to be common to most TNC-2 controllers used for 1200 baud packet.

Summary of the TNC commands		
TNC Parameter	Value	Description or Action
MYCALL	Your Callsign	Default is NOCALL, but you want others to know you are there.
DAYTIME	YYMMDDHHMM	Used if you want to timestamp the packets you are receiving.
MONITOR	ON	Displays all packets on the frequency
MALL	ON	Displays all packets on the frequency (connected or unconnected)
MCOM	ON	Displays the AX.25 protocol with the message
MCON	ON	Allow you to see all packets even when in CONVERS mode
MSTAMP	ON	Monitored packets are timestamped
MRPT	ON	Displays the entire digipeat path for the packets.
CONSTAMP	ON	Connect and disconnect status messages are timestamped
HEADERLN	ON	Header information is displayed on separate line from message text
PASSALL	ON	TNC will accept and display packets that have errors (noise)
PASSALL	OFF	TNC will only accept and display packets that have complete CRC.
CONVERS	<enter>	Mode to type packet message from keyboard directly to the TNC
MHEARD	<enter>	Displays your TNC's "heard" list (updated only when PASSALL OFF)
UNPROTO	CQ VIA ARISS	Most basic string for ARISS to copy, route, and digipeat your packet
UNPROTO	CQ VIA W3ADO-1	Basic string for PCSAT-1 for DAYTIME ONLY operation.

Overview of Operating the ISS Digipeater Using Your Computer's Soundcard and Software



Overview Soundcard and Radio Connection

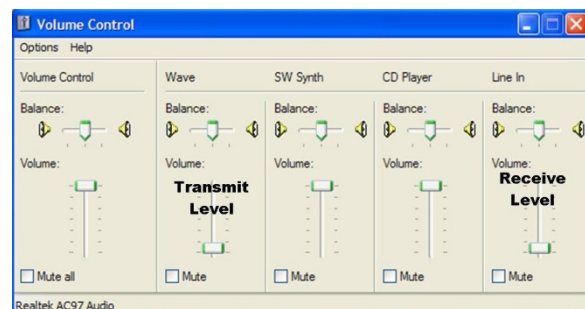
Operating packet without the traditional standalone TNC requires a combination of software and hardware connection.

- Software will generate and decode the AX.25 packet signal using the digital signal processing capabilities of the soundcard in your computer.
- A soundcard interface box is needed to set the proper sound levels between the computer and the radio.
- Push-to-talk (PTT) rig control is often generated by the software by setting selected pin(s) of the RS-232 serial interface. Some radios such as a Yaesu FT-857D will reliably switch between TX and RX function if the VOX levels are set in the radio's operating menus.
- If you already have interfaced your radio to the soundcard for other amateur radio applications such as RTTY, PSK31, JT65, SSTV you are already set for AX.25 ARISS packet operation with the ISS – all you need is to download, install, and configure some free software.

Since the connections between your radio and the soundcard interface of your choosing are specific to your situation we will defer discussion of this because you need to consult your radio operator's manual and the instruction book of the soundcard interface. Careful research before buying an interface box will reveal that many of the leading brands will also sell you an interface cable kit specific to your radio.

Setting Your Soundcard Levels

As mentioned, if you are already using your soundcard for other amateur radio applications such as PSK31, etc. usually the same settings can be used for packet. If needed use the "Wave" slider control to set the transmit level; use the "Line In" slide control to set the receive level.



Install the Software You Need

The software you need for ARISS packet operation is available for free download. The items you will need include:

- **AGWPE** - Written by George Rossopoulos, SV2AGW, and is an acronym for "SV2AGW's Packet Engine". It was originally created as a TNC management utility and has many super features of value to TNC users, plus it has the ability to encode and decode packet tones using your computer's sound card. Download from:
<http://www.sv2agw.com/ham/agwpe.htm>
- **UISS** – Written by Guy Roels, ON6MU designed for UI packet communication (unproto) packet with ISS. This will be your user interface for packet communications with the ISS. This software is free for amateur and non-commercial use. A PRO version is available and donations are welcome. Download from:
<http://users.belgacom.net/hamradio/uiss.htm>

Installation and user guides for the software packages are included on their websites. Here are a few links to websites that will

give you the information needed to get on the air quickly:

- The “golden” reference for sound-card packet configuration and operation is the “Sound Card Packet” site by Ralph Milnes, NM5RM:
<http://www.soundcardpacket.org/>
- Additional help for installing AGWPE is written up in a word document, “An Easy Set Up For Soundcard Packet” by Karl Berger, W4KRL. These are basic instructions for getting started but you will not need the WinPack steps outlined. (We’re using UISS instead.)
<http://www.w4ovh.net/SoundcardPacketSetup.doc>
- Mineo Wakita, JE9PEL has published several on-line references for the installation and use of UISS:
<http://www.ne.jp/asahi/hamradio/je9pel/ui32uiss.htm>
UISS setting up APRS satellite:
<http://www.ne.jp/asahi/hamradio/je9pel/uissagwp.htm>
- The UISS site has a reference page:
<http://users.belgacom.net/hamradio/uisslinks.htm>

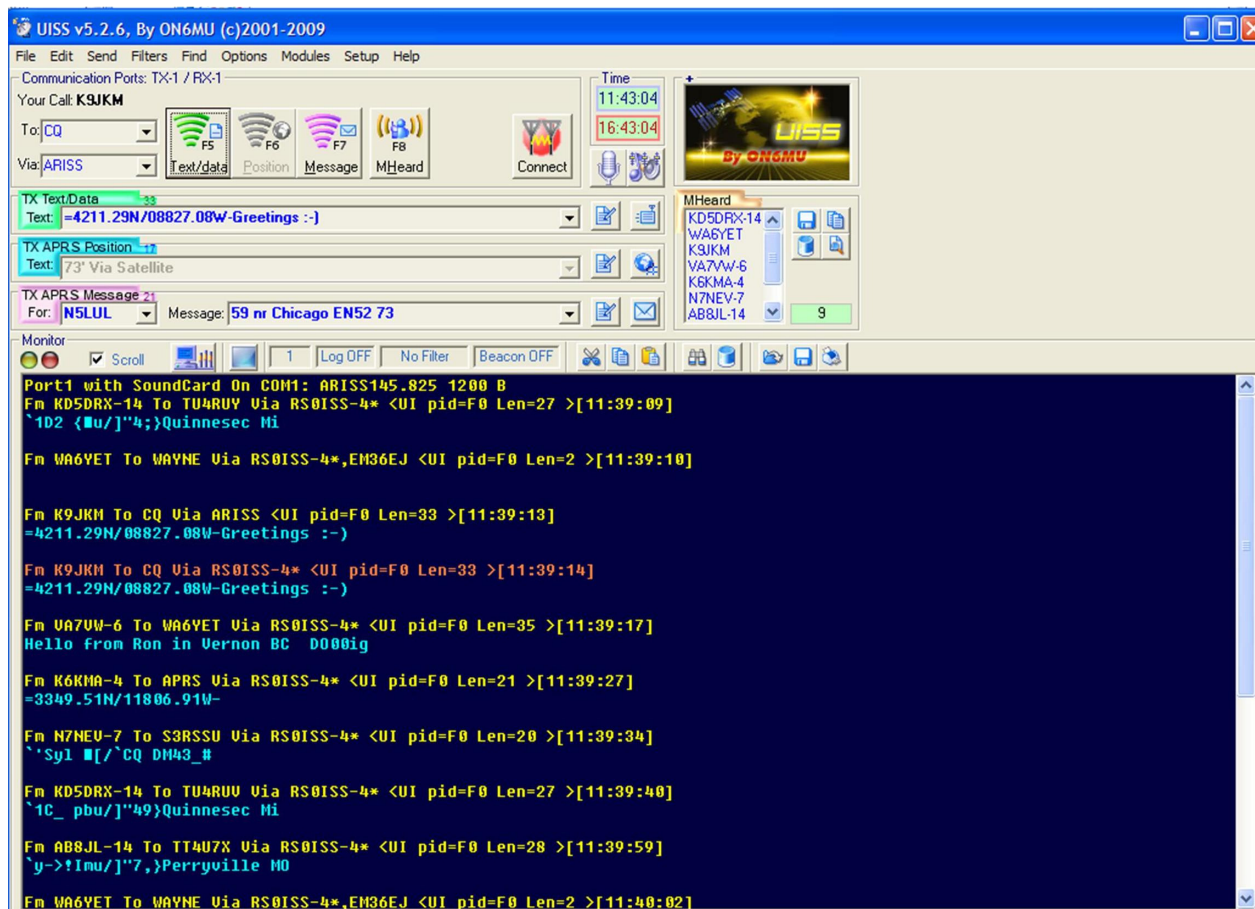
Example Operating Session With the Soundcard

All of the necessary parts are installed ... and the ISS is approaching. Here is an example of an operating session to further acquaint you with this mode of operating.

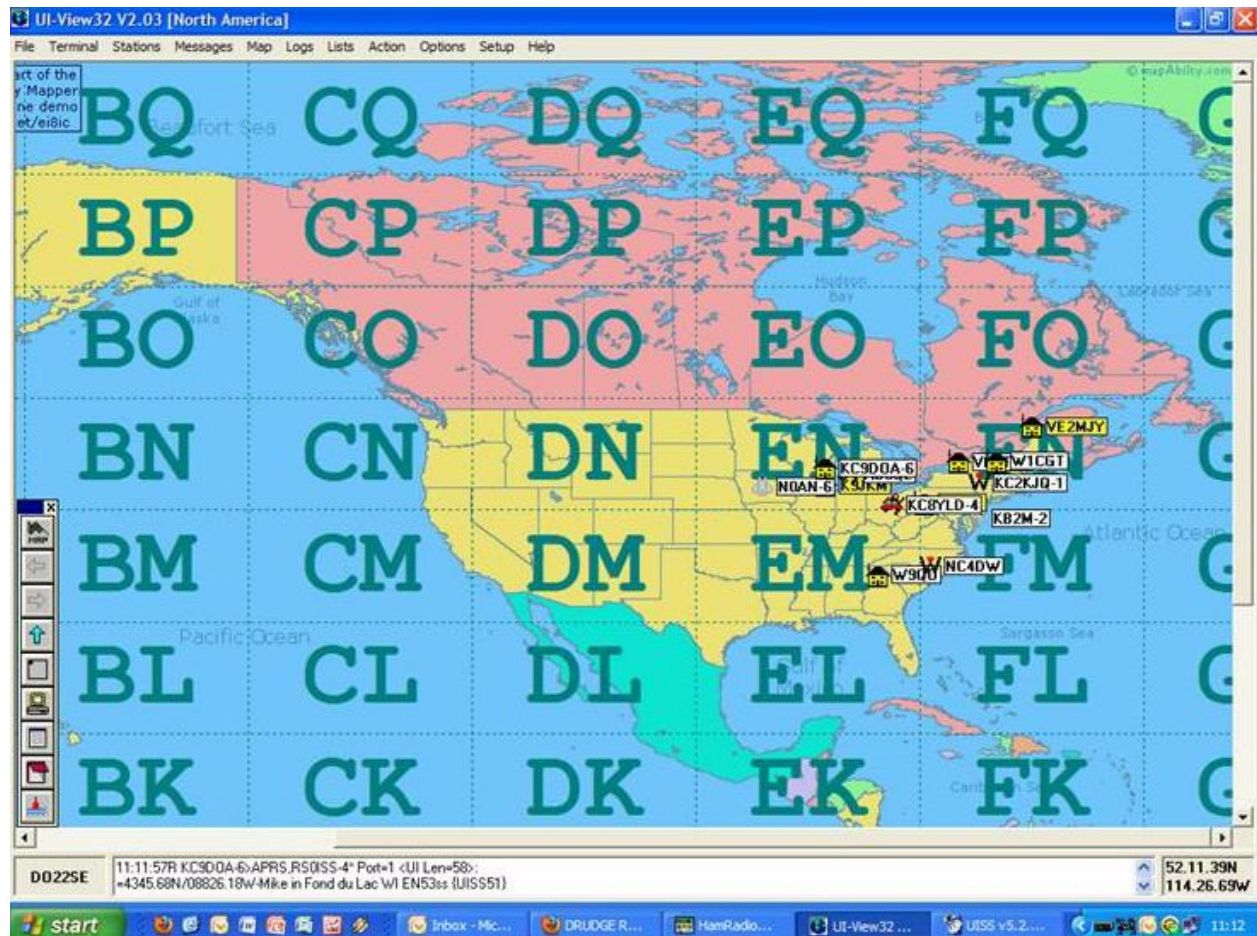
- 1) **Always start AGWPE first.** Click on the AGWPE icon on your desktop and you will see the following splash screen telling you things are running. The splash screen will go away in about 10 seconds. You will also see the AGWPE Packet Engine startup “bubble” appear in the toolbar. You can “X” (to exit) the bubble but AGWPE will continue to run as shown by its icon in the toolbar. You can left or right click on the icon to get to AGWPE configuration settings if you ever need them.



- 2) **Start UISS.** Click on the UISS icon on your desktop and the program will open to the operator screen.
 - a. Your **UNPROTO** string **CQ VIA ARISS** is set by using the pulldown menus in the **To** and **Via** windows in the top/left of the screen.
 - b. The APRS-formatted location information which was also used in the hardware TNC configuration is entered in the **TX Text/Data** window.
 - c. The **MHEARD** command used with the hardware TNC to show who is on the frequency has its equivalent display shown in the MHEARD list on the right side of the screen.
 - d. To transmit my packet configured for digipeating via ARISS **=4211.29N/08827.08W-** just click on the Text/Data button in the top row.
 - e. UISS will show all of the packets being received when the ISS is within range. Your packet will be highlighted when you (and everyone else in range) receives the digipeated packet.



3. Optionally you can display the stations you receive on an APRS-format map. In the example here **UI-View** shows the stations received that were transmitting their location data during a pass of the ISS over the eastern half of North America.
 - a. Start AGWPE first, then start UI-View



In summary the previously mentioned screen at <http://www.ariss.net> will also update in the same manner whether the packet came from a hardware or software TNC.

A Note About a Packet “Hard-Connect” to RS0ISS-11 BBS

In a word ... please don't! The ISS PBBS with the ID RS0ISS-11 operates in the same manner as a terrestrial Packet BBS operates. A “hard-connection” (C RS0ISS-11) establishes a full AX.25 connection which brings the entire messaging handshaking protocol into operation. The handshake messages will faithfully repeat, and repeat, and repeat per protocol until they are properly acknowledged. The usual case is that there are many stations sending packets to the ISS resulting in data collisions when RS0ISS-11 is expecting its handshake. Everyone tuned into the pass will see the endlessly repeating AX.25 handshake bytes until the sequence times out. You may have been out of range for several minutes already but the ISS is still listening for you.

Appendix: Know When to Listen – Tracking Resources

If you have experimented with Amateur Radio satellites you may already own a tracking program which will let you see when the ISS is within range of your shack. If you are new to this phase of the hobby

this section will point you toward several on-line resources that you can use right away without additional special preparation.

Tracking Resources on the Web

This section is geared toward helping the beginning operator track the ISS. You will find several resources on the web to help you track the ISS without needing to install dedicated tracking software. These tracking pages are considered to be “close enough”

in the case of calculating when the ISS is within range of your station. This is because the downlink signal from the ISS is so strong and the 145.825 MHz downlink frequency does not require tracking the Doppler shift for you to be able to make successful contacts.

- The **AMSAT Tools** web page: <http://www.amsat.org/amsat-new/tools/>
 - You can select the ISS by using the pull-down menu:

AMSAT™
Satellite Tracking for ISS

850 Sligo Ave. Suite 600
Silver Spring, MD 20910
1-888-322-6728

Launch Pad | Navigator | Sat Status | Keps | Passes | News | Store | Members | Contact Us | Return

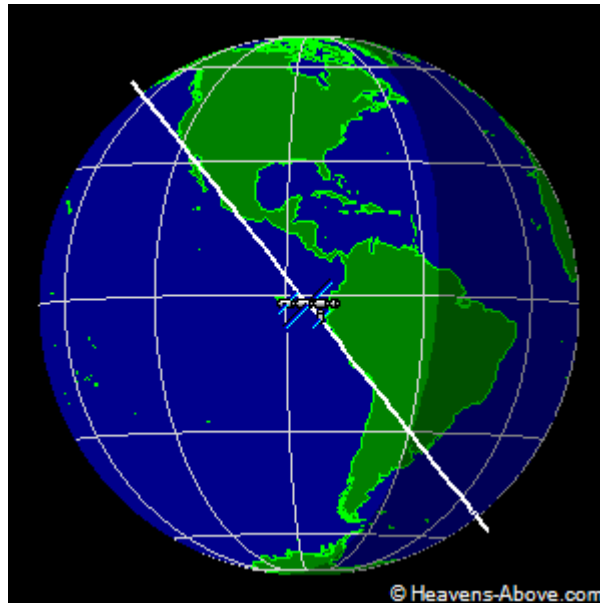
Current Position of ISS
Tue, 11 Sep 2012 17:13:44 GMT (12:13:44 local time)
Current Location: 8.5E 30S

Select a Different Satellite:

Note: Position is approximate and depends on your computer's performance.

For the best in full featured tracking software visit [The AMSAT Store](#)

- The **Heavens Above** web page: <http://www.heavens-above.com> will allow you see the current position of the ISS and many other satellites:



- The **N2YO** page: <http://www.n2yo.com/> is an excellent tracking resource featuring a real-time map that updates in your browser window:

REAL TIME SATELLITE TRACKING

[Whats up in your sky right now NEW](#)

Find a satellite...

[N2YO.com on Facebook](#) [Advanced](#)

ISS (ZARYA)

LOCAL TIME: 10:00:31
 UTC: 15:00:31
 LATITUDE: 50.39
 LONGITUDE: -115.99
 ALTITUDE [km]: 410.52
 ALTITUDE [mi]: 255.09
 SPEED [km/s]: 7.37
 SPEED [mi/s]: 4.58
 AZIMUTH: 303 NW
 ELEVATION: -0.6
 RA: 1h 33m 41s
 DEC: 23° 14' 36"

The satellite is in day light

PERIOD: 93m

[5 DAY PREDICTIONS »](#)

[Make A Donation](#)

RECOMMENDED RESOURCES

[Satellite TV](#)
[IP2Location IP Geolocation](#)
[Find your Magnetic Declination](#)
[Check Google Page Ranking](#)
[Last Minute Stuff](#)

YOUR CURRENT LOCATION

Your IP address: 67.184.171.11
 Latitude: 42.16808°
 Longitude: -88.42814°
 Magnetic decl.: 3° 0' W

Is this incorrect?
[Set your custom location](#)

MOST TRACKED
 ISS (ZARYA)
 DIRECTV 1R
 GOES 15
 GOES 12
 MOLNIYA 1-36
 TOP 50 »

JUST LAUNCHED
 BEIDOU M6
 BEIDOU M5
 METOP-B
 AEROCUBE 4
 AEROCUBE 4.5B
 LATEST 50 »

POPULAR CATEGORIES
 GEOSTATIONARY
 WEATHER
 IRIIDIUM
 GLOBALSTAR
 AMATEUR RADIO
 MILITARY
 TV SATELLITES
 GPS OPERATIONAL

UP IN YOUR SKY
 GPS
 IRIIDIUM
 GLOBALSTAR
 SIRIUS/XM
 WHAT'S UP?

OTHER SATELLITE FEATURES
 ALL CATEGORIES
 BROWSE SATS
 STORM TRACKING
 SEND FEEDBACK
 SATELLITE LINKS

SEARCH DATABASE
[ALERTING TOOLS](#)
[FAQ](#)
[PREFERENCES](#)
[SUPPORT N2YO.COM](#)

Map **Satellite**

Retrieving data... ☒ Draw orbits ☒ Draw footprint ☒ Keep selection centered

- The **ISS Fan Club** web page: <http://www.issfanclub.com/> includes a tracking widget showing the current location of the ISS. It also includes the latest known status of the downlink frequencies as reported by amateur radio stations worldwide:

The screenshot shows the ISS Fan Club website. At the top, there's a navigation bar with links: Frequencies, QSL, IAA, NA1SS DXCC, About this site. Below that, a secondary bar has links: APRS Tracking, Ham Radio Contacts, Images from Space, Forum, Polls, Guestbook, and a search bar. The main content area is divided into several sections:

- ISS Position:** A map showing the ISS's current location over the Atlantic Ocean, with a Google map interface below it. It includes a "User login" section with fields for Username and Password, and a CAPTCHA.
- Photo and Text:** A photo of two men, Joe Acaba and Marcelino Canino, holding a sign that says "The best regards to ISS FAN Club". Below the photo is a text block titled "Joe Acaba (NA1SS) - Marcelino Canino Canino Middle School, Dorado, Puerto Rico on 12 September 2012 at 1728 UTC".
- Voice:** A section titled "Voice" with a link "Add your report". It shows "Last ACTIVE: 21 min 28 sec ago from now", "Downlink: 145.800", "Uplink: 145.825", and "Description: ISS called W4LMS on what she said was Channel 46 and then answered questions till my LOS in Florida. Name: N4ZQ".
- Packet Radio:** A section titled "Packet Radio" with a link "Add your report". It shows "Status: ACTIVE", "Date/Time: 6 hours 34 min ago", "Downlink: 145.825", "Uplink: VHF", "Description: heard station this...", and "Name: f1rxm".
- SSTV:** A section titled "SSTV" with a link "Add your report".

Tracking programs

As discussed, the web tracking screens will get you started and will be quite adequate in many instances for casual operating.

Installing a tracking program on your computer is the next step. I am mentioning this as your second option due to the learning curve with all of their features adding another level of complexity. But, once learned, your own tracking program on your computer in the shack will give you the best level of prediction with display features tweaked for your personal preferences. You will also have the capa-

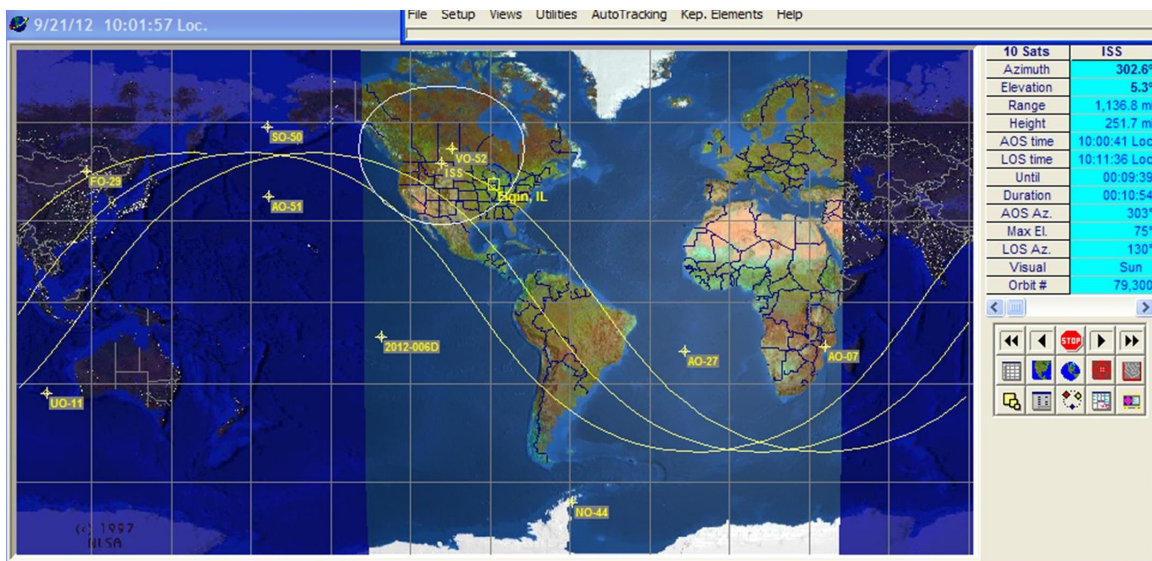
bility to track and display the position of multiple spacecraft. Tracking software will enable many interesting features:

- Real-time position display on a map
- Real-time position data including azimuth and elevation to point your antenna
- Predict future passes
- Advanced features include:
 - Rotor control to automatically aim your antennas
 - Rig control to track the Doppler shift.

Examples of three popular tracking programs for your PC are included on the following pages.

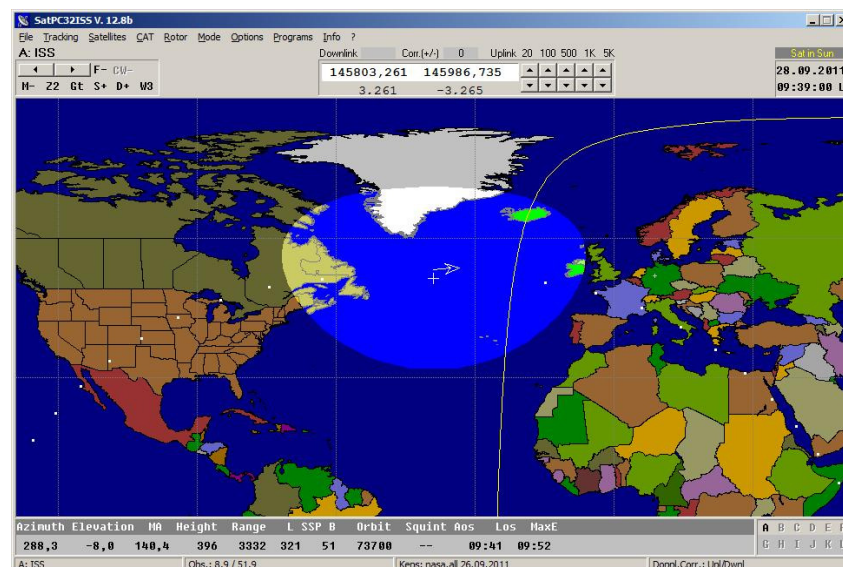
Nova by Northern Lights Software Association

<http://www.nlsa.com/>



SatPC32

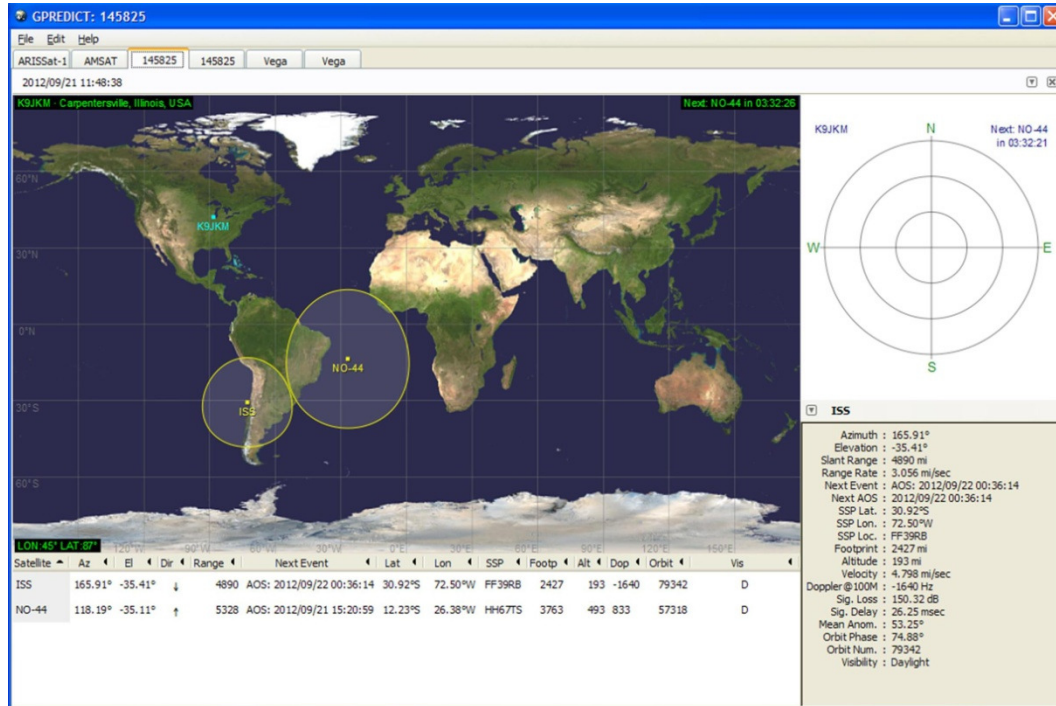
- This program is written by Erich Eichmann, DK1TB. He has donated all the proceeds from the software to AMSAT. You download the software and receive assistance from his website: <http://www.dk1tb.de/indexeng.htm>
- You can the program in a demonstration mode to try it out for free. You can purchase this software from the AMSAT store on-line: http://store.amsat.org/catalog/product_info.php?cPath=2&products_id=50
- After purchasing the software, Martha will send you a license key to use to unlock all the features of the software.



GPredict

<http://gpredict.oz9aec.net/>

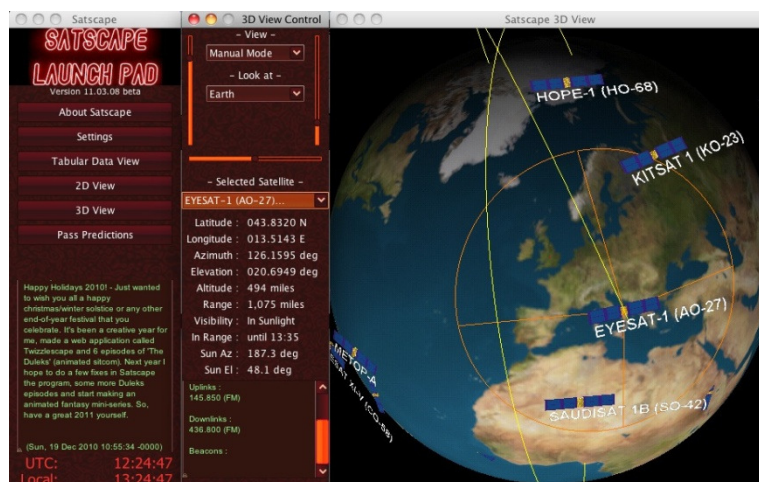
Gpredict is a real-time satellite tracking and orbit prediction application. It can track an unlimited number of satellites and display their position and other data in lists, tables, maps, and polar plots (radar view). Gpredict can also predict the time of future passes for a satellite, and provide you with detailed information about each pass. Gpredict is free software licensed under the GNU General Public License.



SatScape

<http://satscape.info/satscape/>

SatScape is satellite tracking program for Windows, Mac OS and Linux.



“Working Satellites with a homebrew setup: Cuban style”

by Hector L. Martinez, CO6CBF, co6cbf@amsat.org

Since I heard about SuitSat-1 from the National Television of my country, I was encouraged to research about it, about ARISS and space communications in general. I had not heard about this part of our hobby before. I was really surprised when I discovered the great amateur radio activity that exists in space. At that time, I was 15 years old and was studying at the Electronic Technician school of my city. I got my first radio license at 11 years old as CL9CBF, and built my first 160m transceiver following the instructions from Raul, CO6GB - a radio operator of my Radio Club. I was very active on 160m.



The only radio available for satellites was a broken 2m Yaesu FT-23R HT which my grandfather bought for me. I fixed it, following the instructions from Javier CM6WB - another ham of my Radio Club. I tried to receive SuitSat-1 using this radio and a homebrew 6-element Yagi which I made to operate through the local repeaters. As I had been studying about antennas for satellites, I bent the Yagi's boom skyward and moved the small tower in front of my shack's window, ready to point it by hand through the window.

At the same time, I was trying to build my first PC computer with recycled parts. It was ready for SuitSat-1, running an unregistered version of WXtrack on Windows 98. Despite not hearing anything from the spacecraft, it was a great experience for me. Looking for information about it, I learned about the marvelous world of AMSAT and the space projects which involved amateur radio.

I built the interface to connect the FT-23R to the computer and made everything to work the ISS digipeater. The first signal seen on the screen was from YV6BFE. I also tried to receive the meteorological pictures from the NOAA weather satellites. After some weeks, I had the first contact with the International Space Station's crew. An unforgettable moment in my life!



At that time, I kept in my mind that operating through the Satellite transponders was impossible for me. I never had seen any 70cm radio, or any UHF homebrew radio project. I had not known any satellite operator in my country either.

My first satellite setup:

When I finished the technician school, I began to work as an electronics technician. I had my own email and an Internet account. I continued looking for any 70cm radio or any UHF

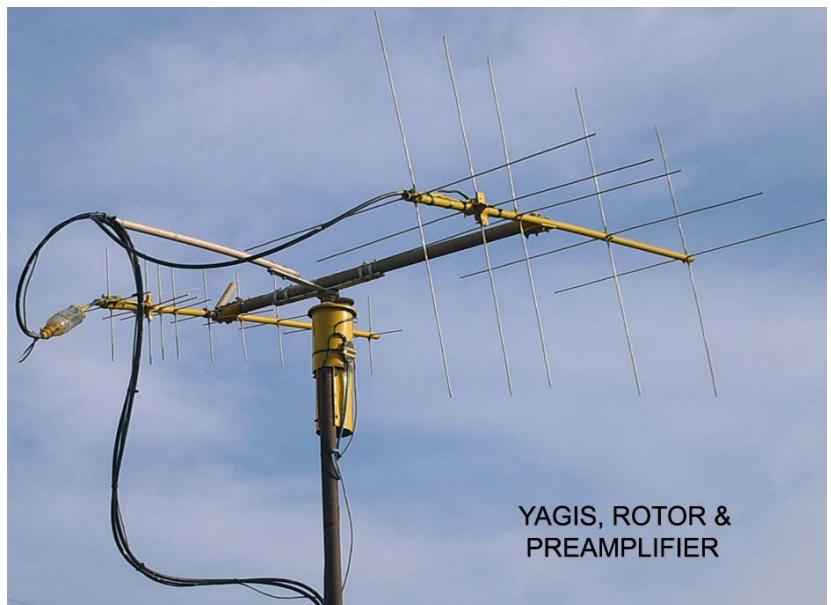
scanner, but it has been really difficult for me to find one. There are no shops or RadioShack stores available to buy anything related to amateur radio.

I found some 70cm downconverter designs online, and asked for help in some email lists about any other designs in order to choose the most complete and achievable project. This one came from Bill NZ5N who sent me a project published in the March 1983 QST by John W6IOJ. It is a great project with a detailed "Know How"! As the project doesn't require highly sophisticated test equipment for alignment, the article itself shows how to build the needed test



equipment. Even though this was written in 1983, it was still relevant for me. While there are plenty of high performance downconverters, most of the parts required to build them are not available in my country. It was just what I was looking for!

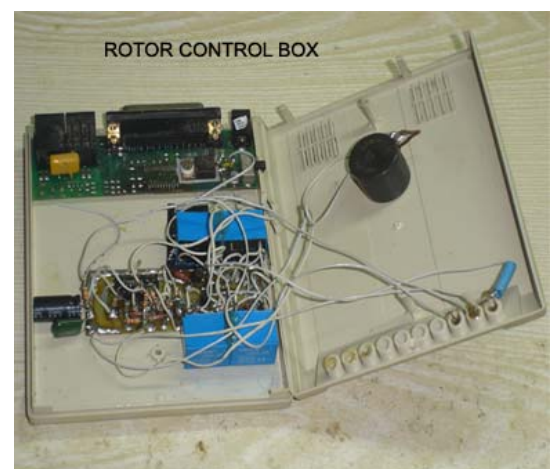
I constructed everything carefully as John described, beginning with the test equipment. All the electronic parts were found in my "junk box" and in a broken Yaesu FTC-2640 2m radio. I did not have a printed circuit board to



YAGIS, ROTOR &
PREAMPLIFIER

make the circuits, so I built it in three TV tuner boxes without circuit board. I used a box for each module: local oscillator, mixer and RF-amplifier. This method made the project very easy to assemble. It was my first UHF homebrew construction, and I cannot say how satisfied I was when I tested each module and everything worked properly.

I had thought in antennas too. While I was working on the converter, my grandfather - who is a smart mechanic - was building some pieces to rebuild a blood pump's motor reducer from a discontinued



dialysis machine. We used it as the main part for the azimuth rotor. I designed the circuits for the position reference and the remote control box. The rotor control box was constructed into a FAX modem case.

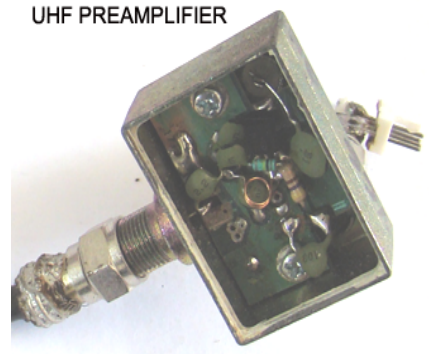
I designed two circularly-polarized Yagis, 18 elements for UHF and 10 elements for VHF. I simulated and optimized these in software called MMANA, and the project was ready to be built. The calculations were done for the parts that I had in my "junk box". I used 30mm PVC pipe for the booms, and for the elements 4mm aluminum wire. The transmission lines were RG-58 coaxial cable.



The rotor and antennas were assembled in my backyard at four feet over the ground to test its performance before going on the roof. The system was tested and it worked as it was expected. So, I had everything ready for the "smoke test", my first satellite contact.

My first satellite contact was on January 27, 2011, with John K8YSE on AO-51. Another unforgettable moment in my life! After that, I spent around two months working on the tower and the UHF preamplifier. I chose a mast-mounted DF9CY preamplifier design and I built it into a TV splitter case. It was tested with the same equipment built for aligning the converter.

UHF PREAMPLIFIER



We installed the rotor, antennas and preamplifier on the tower. Since that moment, I have been on satellites almost every day!

First portable operation

After about a year on the FM birds. I obtained the first satellite VUCC in my country and other AMSAT awards. This was a great accomplishment for me. While I was very active on satellites from home, I was improving my FM setup until I could carry it in my backpack. I constructed a YO3BAL 70cm/2m downconverter, which spent a long time at the workbench due to the poor description of the design I had and the inappropriate circuit board material I used. Finally, I got it performing properly, but it did not perform as well as my 70cm/10m converter.

I rebuilt an SSB HF receiver which I made for other uses as a FM 10m receiver. I tried to reduce the weight and size as much as I could. When the work was finished I tested it together with the 70cm/10m converter. Its performance was very good.



In August 2011, my brother Franklin CL6BFC, my girlfriend, and I planned a vacation trip to Trinidad city and Rio Hondo. I thought it would be a great opportunity to do the “smoke test” with my portable setup and activate a rare grid square. I made an IOio antenna and tested the system from home trying to receive AO-51 running both configurations:

- IOio antenna, 70cm/2m downconverter, 2m HT
- IOio antenna, 70cm/10m downconverter, HF receiver.

The second configuration worked better, but it was a little more complicated to use without any assistance.

Finally, I carried the two configurations and a 12V 7A gel-cell battery to power the system. It was my first portable operation on satellites, and it was fantastic. I operated from the EL91/FL01 grid boundary, and used both configurations. During the very early morning AO-51 passes around 5:30 AM, I woke up and used the first configuration with limited RX capabilities. During the afternoon passes, I used the better gear with the assistance of my brother and my girlfriend. We had 20 contacts in four AO-51 passes, and we operated from two grids never activated on satellites!

SSB Satellite Setup

Since I set my eyes on the linear birds, I had been looking for any 2m multimode radio. Once again, it has been really difficult to find one.

I tried to convert an old 2m FM transceiver into a CW transmitter. I disconnected the MIC preamplifier circuit, I kept the TX activated, and switched the RF drive transistor by a switch circuit added and commanded by the CW key. The experiment worked successfully, and I had my first contact on AO-7 mode A on April 24, 2011, with Gary K4MF.



Thinking about something more serious, I began to find information about any homebrew SSB 2m transceiver or transverter project to complete my gear for the linear birds. I found some interesting and detailed projects online from Gaetan ON4KHG and Janne OH1SDR, but most of the parts required to build them are not available in my country.

The most achievable 2m transverter project came from Manuel CX9BT. He designed and constructed it for EME purposes. The project looked wonderful, and I had the opportunity to chat directly with him by email and radio on the 10m band. The project required some specific

parts: the MC145151 synthesizer, the SP4541 prescaler, the PIN diodes, the mixer DBL, the 5W Hybrid Power Amplifier, some GaAsFETs, and some dual-gate FETs which are not available in my country. Manuel sent me all these parts and some others for future projects!

I started to construct the transverter and was testing circuit by circuit as Manuel was telling me. It was really difficult for me to fix the synthesizer exactly at 116.00 MHz. The project was constructed in a discontinued PH meter laboratory instrument case. When the transverter was finished and aligned I did the "smoke test" on FO-29. My first contact was on January 31, 2012, with Robert, AK5V.



When I finished the transverter, I listened for VO-52 and I was surprised with the great signals coming from the transponder and beacon. I was encouraged to work on another project to add the transmission stages for my first 70cm/10m down converter. I had to modify the original project but it was not difficult as the main part was done before. I modified the same CX9BT design with some references taken from the JF1OZL 70 cm transceiver project. I built the switch stages, attenuation stage, bandpass filter, and power amplifier. The majority of the electronic parts were found in my "junk box". The few remaining items like high Q trimmers and high frequency low-noise transistors impossible to find here, were donated for Bill, W3XS.

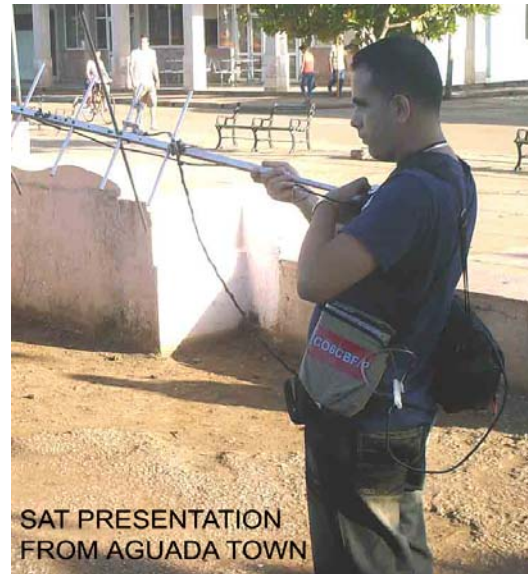
I had my first contact on VO-52 on February 28, 2012, with Walter, WP4T. I was running around a watt, and Walter gave me 57!

Current satellite gear and future projects

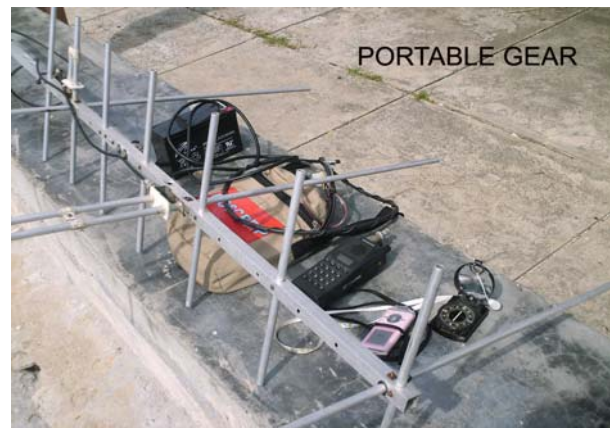
In order to improve the Intermediate frequency stability for the transverters, I bought a Yaesu FT-757GXII in good shape but with some transmission issues. I researched it and looked for any assistance in the Fox Tango International web site. In this occasion the help came from Carol W4CLM and David W6NFU. I substituted all the switching diodes in the RF board as they told me, but the problem with the RF power continued. So I decided to substitute the TX mixer IC (ND487) which has four diodes. I matched four BAT 41 diodes and connected these under the circuit board to try the RF power level again. Fortunately, the radio was fixed! It is my first commercially-made Ham radio!

When I am at home, I combine the 757 with my homebrew transverters which is a great advance among my homebrew HF transceivers. Now I am able to tune FM in 2.5 kHz steps, which is a great help to receive SO-50.

My local area is very hot. I live in the city, which has a lot of buildings with amateur, broadcasting, repeaters and other stations. So I constructed a cavity preamplifier which Domenico I8CVS described in a great Italian article. Before that, I had TV interference on the downlinks of SO-50 and AO-27. When I began to use the preamplifier, the interference disappeared. It allows me an excellent full-duplex capability without desense problems.



In order to handle my portable gear easier, I found a great solution - I installed the YO3BAL 70cm/2m downconverter inside a mobile 2m radio that had a damaged transmitter. I removed it, and then installed the downconverter. Now it is easier to operate from anywhere, I hold the 2m FM mobile radio with a strap around my neck, the HT in one hand and the homebrew Arrow antenna with preamplifier in the other hand. I use a 2m Kenwood TK-270 handie talkie for transmitting, a 12V 7A gel-cell battery into a backpack to power up everything, plus a portable digital MP3 recorder to log the contacts.



I tested some preamplifiers on my homebrew ARROW antenna including a PR40 kit that was donated by Omar XE1AO. The preamplifier on the ARROW improved my capabilities to receive the satellites during my portable operations. I worked Yuri UT1FG/MM on AO-27 with under a degree of elevation!

I am preparing to improve my station to work FO-29 on the horizon. Cubans cannot operate on the 432 MHz (AO-7's uplink). So FO-29 is the only chance to reach long distances on the satellites. I am constructing a 2m 50W linear PA and two long Yagis like M2's 2MCP14 and 436CP30. I am trying to add the elevation capabilities to my homebrew rotator,



keeping in mind the local availability of pieces that we recycle from many sources. I plan to install the antennas at 95 feet on a nearby building.

I have spent a long time at the workbench constructing my gear for satellites. It has been a really long time, but I have enjoyed it!

I have worked 49 of 50 US states, and 487 grids squares. I have operated from six Cuban grid squares (EL83, EL91, EL92, EL93, FL01 and FL02) most of them have never been active on the satellites. In less than 2 years on satellites, I can see 4460 contacts in my log!

Here in Cuba, there are only a few satellite operators.

The amateur satellites are a strange world for the majority of Cuban hams. In order to promote Amateur Radio by Satellite, we formed the first Cuban Satellite Group (GROS). We are trying to encourage operators to join us on this fascinating ride. We have done several satellite presentations from radio clubs, universities, high schools, and parks. We have won a lot of satellite enthusiasts. My hope is not only involving more hams on satellites, but motivating young people today towards careers in science, math and technology. I will never forget my first time hearing myself on the transponder downlink. Even though it was almost two years ago, my heart is still excited when I hear myself on the downlink!

I want to say "thanks" to all my friends who have helped my satellite career. I am very fortunate to have known each of you. I truly appreciate your assistance, advice, help and friendship in general! Thanks so much my friends!



Applying the Codec2 Low-Bitrate Voice Codec to Amateur Satellite Operations

Bruce Robertson, VE9QRP
Revision 2012-10-06

Introduction

Anyone who has used an mp3-player knows how programs that encode and decode digital sound (so-called 'codecs') can change the world. Transforming the impractically large music sound files into ones that are much smaller, yet still pleasing to the ear, these make it possible to carry in one's pocket a 4 GB library of hundreds of hours of music that once would have filled a room, all thanks to the decoding software in the player.

In a related manner, the mobile phone industry is built on codecs that are specially tuned to encode and decode voice, thereby reducing, in this case, not storage requirements, but rather the resources needed to make a call. Just as with an mp3-player, the important factor is how much computer information (measured in kB, for instance) it takes to encode a certain duration of speech (measured in seconds): a factor known as 'bit-rate'. The commonly used AMR system adjusts to the situation and uses codecs with bit rates varying from 12.2 kbit/s to a very small 4.75 kbit/s. For radio use, lower bit-rates mean a better signal-to-noise ratio for the same amount of power, quality of antennas, etc.

The advantages that the cellphone industry gains from voice codecs apply also to amateur radio operators, especially those of us who use amateur satellites. Historically, indeed, amateurs have been happy to trade the fidelity of voice reproduction for better 'reach': voice compression circuits and microphones especially made for DX communications are two examples of this approach. To find this advantage in digital voice codecs, however, amateurs need very low bit-rates, lower than the lowest AMR codec.

Such specialty codes have existed for some time, and various 'digital voice' systems based on these are in use by amateurs.[1] Perhaps the most popular is the AMBE codec used in the D-Star standard. It operates at 2400 bit/s, and uses an additional 1200 bit/s in encoding and forward error correction.

History

However until now, non-technical factors have deterred many amateurs from whole-heartedly adopting digitally encoded voice. This is because no low-bitrate codec has been available under a open-source license; and typically, in order to preserve their intellectual property, the owners have required that the codec be implemented in hardware, with a separate chip required to perform the encoding and decoding. (It is for this reason that one must have a USB dongle to hook a computer up to use the audio component of the D-Star network: although in theory the computer itself has all the power needed to perform the codec, the dongle contains a specially devised codec chip.) This situation not only makes the use of low bit-rate codecs more expensive, it also makes it difficult to perform the sorts of experiments that might fine-tune a codec for niche applications, like amateur satellite operations.

Bruce Perens, K6BP, recognizing this need, encouraged David Rowe, VK5DGR, to take up the cause, specifically by repurposing the work in his Ph.D. thesis. David has not only worked openly and assiduously, but he has built an effective community of co-enthusiasts, producing Codec2, an open-source low-bitrate voice codec ideally suited for amateur radio operators. This work so far has won him the ARRL technical innovation award for 2012 and the best talk of show award at linux.conf.au.

Software

Codec2 is available as free and open-source software, downloadable via svn.[2] Currently, this repository provides a range of codecs, from 3200 bit/s to 1200 bit/s, with an experimental 4000 bit/s codec in early development. These are accessed primarily using the command-line programs `c2enc` and `c2dec`, which for experimental purposes can be integrated with the audio system of a Linux computer, and with the Internet, by means of simple shell pipes.

David has also developed a FDMDV modem for Codec2, designed especially for HF digital voice use, but easily repurposed for experimental use on amateur satellites with linear transponders.

Kristoff Bonne, ON1ARF, has developed a GMSK modem, originally for use in exploring the D-Star protocols, but now nicely integrated with Codec2 running at 1400 bit/s.

Dave Whitten, KD0EAG, is undertaking the task of integrating David Rowe's work into a GUI application for the Linux and Windows platforms, called FDMDV-2.

How does it sound? David's website provides several examples.[3] I also have posted a YouTube video of an Internet conversation between myself and Paul Saville, ZL3IN, in early 2011.[4] We used a simple shell script that I wrote to send and listen to Codec2 packets.[5] To me, this experience was the true test because Paul and I had never met or even heard each other's voice before. Nevertheless, we were able to have a real 'rag chew', learning about our families, hobbies and other interests.

There have been many improvements to Codec2 since that conversation, and the best way to find out what it sounds like is to try it yourself!

Hardware

While most development of Codec2 is done in on Linux PCs, the code has been ported to a variety of devices. For instance, I have cross-compiled the encoding software for the Nokia N800, whose CPU is a 330 MHz ARM11 chip, and to the popular experimenter's platform known as the 'Pandaboard', which comprises a ARM Cortex-9. (An attempt last year at the PIC32 environment was not so successful.) Peter Lawrence reports success with a \$20 development board with an ARM Cortex-M4F CPU.

Because its floating point routines have not yet been ported to an integer library, Codec2 has not yet been run on the even cheaper hardware that lacks a floating point unit.

Use in Amateur Satellites: Experiments With Today's Satellites

The suite of programs described above allow amateurs to experiment with, and improve, Codec2 right now. The FDMDV modem can be used in brief experiments on linear satellites such as VO-52. The challenge here is, of course, tuning the downlink and Doppler correction, and David is open to improvements on this front. He notes that the demodulator frequency offset estimation is currently hard-coded to 1200 +/- 200 Hz, and that, once in sync, it can track a few Hz per second of Doppler. A much wider bandwidth frequency offset estimation would be helpful and should be achievable along with better Doppler tracking.

Secondly, I note that with only a 5dB signal-to-noise ratio and 2.5 kHz bandwidth, the average amateur FM satellite has a theoretical bandwidth of $2.5 \log_2(1 + 3.2) = 5.2$ kbit/s. Might appropriately designed narrow bandwidth modulation techniques fit two, or even three, conversations on a single FM satellite channel? (This challenge would certainly put the lie to the common nickname 'EasySat'!)

Use in Amateur Satellites: A Cubesat Codec2 Demonstration Mode

The most important benefit of Codec2 for amateur satellite users is that it can bridge the gap between satellites as a means of communicating digitally and a means of communicating voice. Amateur satellite construction and use has undergone a great change in the last decade; and many feel that this has not been for the better. While in the long term the cubesat standard, coupled with technological advances like software-defined transponders, will provide us with a reliable source of relatively low-cost launches for voice communications, the last few years have been trying ones for the many hams who prefer, above all else, to *talk* to other hams, not to collect telemetry or transmit data. Yet when we now have the ability to transform voice into very low-bitrate data cheaply, easily and on all platforms, even the most humble cubesat is no longer a mere 'beep-box' (as some pejoratively call them), but a potential means of exploring voice communication.

However, for this to come true, cubesat developers must design their satellites' downlink with possible Codec2 experimentation in mind. While not all these design decisions can be determined easily, some are obvious. A compatible data modulation mode needs to be implemented. For instance, experiments reported in the Codec2 email list prove that the popular AFSK/FM mode does not make a good platform for Codec2, because its 1200 bit/sec channel leaves no room for error correction of the 1200 bit/sec data stream. But AFSK/FM has many other disadvantages and can be improved on in many respects, as Karn argued in last year's symposium, and as our experience with ARISSat-1 showed.[6]

Use in Amateur Satellites: A Digital Bent-Pipe Mode

A more advanced platform for Codec2 experimentation would also provide the uplink necessary for real-time communication, likely at the same rate as the downlink. Using this to make a bent-pipe communication mode for digital data, the digital satellite becomes a voice communications satellite.

What sort of modulation technique and how much error correction would be most helpful for LEO satellite digital voice applications? Could, for example, some fading be mitigated at the cost of a slight delay in the link? BPSK1000's 16 second convolutional interleaver would tax the patience of any listener, but perhaps a middle road could be found. What improvements could be made to groundstation software so that voice signals can be 'found', perhaps with a SDR? These are all worthy questions for an ambitious and innovative cubesat project. As an organization of hobbyists, we can assure student researchers working on such a project that we will provide a large number of users to explore these problems with them.

Use in Amateur Satellites: An In-Flight Modulation Mode

In the long term, perhaps the most practical use of this software for the average AMSAT user would see a Codec2 modulator running on the satellite itself, converting FM or SSB audio uplink(s) into a more narrow-band digital downlink. This split mode would greatly simplify the use of digital voice, since only the downlink side would need to be established by the amateur using a new technique. It would also provide the satellite with the greatest advantage of the system: less power needed for a given number of channels and link quality. Of course, this advantage would only be realized if on-board CPUs could efficiently encode Codec2, and therefore experiments need to be conducted to see at what costs typical hardware for software-defined transponders can run this process.

Conclusion

Codec2 offers the AMSAT community a more efficient and/or more robust means of voice communication than those presently in common use. Amateur satellite operators can and should experiment with this mode, both terrestrially and via space links. Most importantly, designers of future spacecraft using the amateur bands should seriously consider meeting the challenge of providing a digital voice mode compatible with the low requirements of Codec2.

Notes

[1]Hallas, Joel (W1ZR). "AOR ARD9800 Digital HF Voice Modem" *QST* Feb. 2004. 80-81.

[2]<http://freetel.svn.sourceforge.net/viewvc/freetel/codec2-dev/>

[3]http://www.rowetel.com/blog/?page_id=452

[4]http://www.youtube.com/watch?v=_k-nhHE6CrI&feature=plcp

[5]<http://ve9qrp.blogspot.com/2011/01/cq-codec2-calling-cq-codec2.html>

[6]Karn, Phil (KA9Q). "The BPSK1000 Telemetry Modem for ARISSat-1" *Amsat Symposium Proceedings 2011*.

Simulation of Historical and Future AMSAT Missions using NASA's Open Source “General Mission Analysis Tool”

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Future AMSAT missions to place communications payloads in high altitude orbits will almost certainly involve the use of electric propulsion to move the satellite from an initial orbit to a more desirable orbit that will support a long-lived communications mission (1).

AMSAT will need to acquire suitable software tools to plan and execute such continuous thrust missions. Mission planning software must model all of the forces acting on a satellite including solar and lunar gravity perturbations, solar radiation pressure, atmospheric drag and a high order Earth gravity model and must integrate these effects over a long period of time to predict the orbital behavior of the satellite months or years into the future.

Satellite tracking programs that most hams are familiar with do not model these effects, they depend on frequent Keplerian element updates to incorporate the most recent radar tracking data into their predictions. Since radar tracking data is not available for missions that have not yet flown, we are entirely on our own in attempting to predict their future behavior.

Long time AMSAT members will recall the long range orbit simulations first published in the early 1990's (2, 3, 4) that predicted the eventual decay of AMSAT-OSCAR 13 due to solar and lunar gravity perturbations on its highly elliptical orbit. A variety of computer models were run on everything from Cray supercomputers down to tiny microcomputers, all of which predicted that the perigee height of AO-13 would decrease to about 600 km in 1992 and rise again to 800 km in 1994 before finally dropping again to enter Earth's atmosphere in the fall of 1996. Most noteworthy of these programs was James Miller G3RUH's Integrator program(5), written in BASIC for a 3 MHz 6502 microcomputer.

While studying and attempting to compile the source code for the G3RUH Integrator program over the past summer, I became aware of a recent open source beta software release from NASA Goddard Space Flight Center, the “**General Mission Analysis Tool (GMAT)**” (6). GMAT is free [in both senses: Libre and Gratis] open source software. NASA intends to further develop GMAT as an open source tool for future mission design to reduce its dependence on closed source proprietary software tools, and welcomes public input to this effort.

The professional (paid) version of Satellite Tool Kit, an industry standard orbit simulation program, is also capable of simulating low thrust trajectories but software licenses are very expensive.

As with many open source software projects, documentation for GMAT has not kept up with software development, and although an online user forum exists, quick answers to vexing problems are not often forthcoming, so that a GMAT user needs to have some degree of independence in figuring out how the software works. The source code is available to assist in this effort.

To learn the operation of GMAT and to validate its use in simulating a real life satellite mission, I began by revisiting the orbital decay predictions of AO-13. After some initial learning experiences, within about a week I was able to produce decay predictions that closely matched the historical NORAD tracking data (figures 2, 3, 4) and the results of the G3RUH program (figure 6).

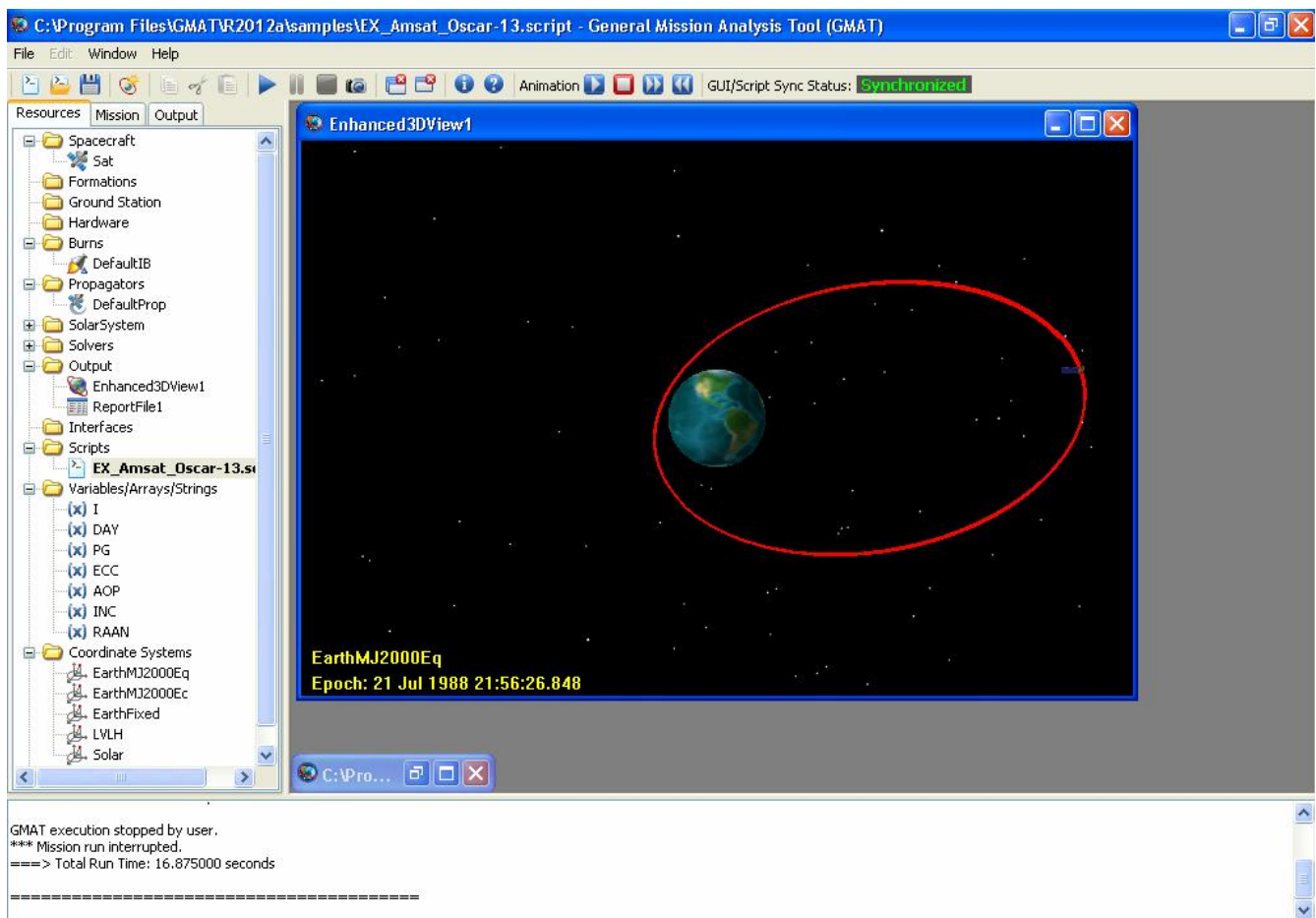


Figure 1: NASA General Mission Analysis Tool

The AO-13 simulation takes 2 hours 40 minutes to run on a 1.7 gigahertz Pentium 4 when propagating the mission orbit from 1988 to 1996. The simulation is very sensitive to initial conditions. After some experimentation I ended up using the same initial “smoothed elements” that G3RUH used to start up his program. The Mean Motion from the input element set must be converted to Semi Major Axis for input to GMAT.

The plotted NORAD data does not show the sinusoidal variations in the orbital inclination that are predicted by both GMAT (figure 3) and G3RUH's program (figure 6). Published NORAD elements are not intended to be instantaneous osculating values, rather they are averaged data sets designed explicitly to feed into the SGP orbit propagator algorithm as used in many popular satellite tracking programs.

The GMAT program aborts the run when the perigee height falls to 150 kilometers, warning that the “RungeKutta integrator accuracy settings will be violated with current step size values.” This is caused by inaccuracies in the atmospheric drag model below that height. It is important to note that atmospheric drag was not a contributing factor in AO-13's orbital decay until the final months of the mission. The loss of perigee height from 1988 to early 1996 was entirely due to solar and lunar gravity perturbations on the highly elliptical orbit, which caused no loss of kinetic energy from the satellite but adjusted the eccentricity of the orbit until it eventually intersected the atmosphere.

As G3RUH pointed out in his 1992 paper (3), a small change in initial conditions would have resulted in

a very different outcome for AO-13. Figure 5 shows the simulated behavior of AO-13 with a 15 degree reduction in the initial RAAN. In this simulation the satellite perigee would have remained above 400 km and the satellite would have survived at least through 1998.

Following the successful simulation of AO-13's orbit, I next turned to the ARRISsat-1 mission, which was deployed from the airlock of the International Space Station on August 4, 2011 and decayed on January 4, 2012. For this simulation the spacecraft mass was set to 30 kilograms. The integrator was initialized by feeding in the averaged Keplerian element data for the ISS over the two weeks prior to deployment, taking care to avoid any known thruster burns on the ISS. GMAT assumes a spherical satellite (7), a 60 centimeter diameter sphere was chosen since it has the same volume as the rectangular ARRISsat box. The drag coefficient was experimentally adjusted until the time interval from deployment to reentry matched the actual ARRISsat-1 mission duration of 153 days (figure 7), the final value ended up as $C_d = 0.70$. The objective of the simulation was not to predict when ARRISsat-1 would reenter Earth's atmosphere but to determine how much rocket thrust would be needed to prevent its reentry.

The GMAT program aborts the run when the perigee height falls below 100 kilometers, with the warning that "The Jacchia-Roberts atmosphere model is not available for altitudes below 100 km." The program takes 42 minutes to simulate the 153 day mission of ARRISsat-1.

As this volume of the AMSAT Symposium Proceedings goes to press, I am learning how to add a propulsion system to the satellite and to control thrust vectoring. GMAT has a rather complicated system to model the performance of rocket thrusters and fuel tanks on the satellite. Thrust is not entered directly but is computed from the specific impulse and propellant flow rate. The current level of support for electric propulsion systems in the GMAT documentation and script examples is sparse, but may be expected to improve in the future, as there is a great deal of interest in this method of propulsion inside NASA and by the space industry in general. I hope to have some interesting results to present at the symposium later this month.

Future projects on the to-do list include:

1. Add an electric thruster to the ARRISsat satellite and model scenarios by which the altitude and orbital lifetime of the satellite could be increased.
2. Model a method by which AO-13 could have been saved if we had had an electric plasma thruster on-board the satellite
3. Model how a future Molniya satellite could be deliberately commanded to execute a similar destructive reentry at the end of its useful mission,
4. Model the behavior of the Planetary Society's "Lightsail" mission.
5. Continue studying and modifying the much simpler G3RUH Integrator program to add electric propulsion thrust to the other modeled forces, so as to better define and understand the issues involved in navigation of low thrust satellite missions.

**"Get to low-Earth orbit and you're halfway to anywhere in the solar system."
attributed to Robert A. Heinlein**

References:

1. **Hall Effect Thrusters for AMSAT Satellite Missions: A Report from the International Electric Propulsion Conference**, Daniel Schultz N8FGV, Proceedings of the 27th annual AMSAT-NA Space Symposium, Baltimore, MD, 2009
http://www.qsl.net/n8fgv/2009_AMSAT_paper.pdf
2. **Chaos: The Eccentricities of Eccentric Orbits**, Tom Clark W3IWI and Erricos Pavlis
Proceedings of the 8th annual AMSAT-NA Space Symposium, Houston, TX, 1990
3. **May the Force Be With You**, James Miller G3RUH
AMSAT-UK Oscar News December 1992, and AMSAT-NA Journal January/February 1993
4. **The Re-Entry of OSCAR-13**, James Miller G3RUH
Proceedings of the 12th annual AMSAT-NA Space Symposium, Orlando, FL, 1994, and AMSAT-NA Journal May/June 1995 <http://www.amsat.org/amsat/articles/g3ruh/114.html>
5. **G3RUH Integrator program:** <http://www.amsat.org/amsat/articles/g3ruh/114/basic.txt>
C Language version by W4SM: <http://www.qsl.net/n8fgv/G3RUH-Integrator-C-source.zip>
6. **NASA General Mission Analysis Tool:** <http://gmat.gsfc.nasa.gov/>
7. Google: “Spherical Cow Joke” http://www.physics.csbsju.edu/stats/WAPP2_cow.html

My thanks to the Celestrak bulletin board <http://www.celestrak.com/> for historical NORAD data and James Miller G3RUH for helpful discussions.

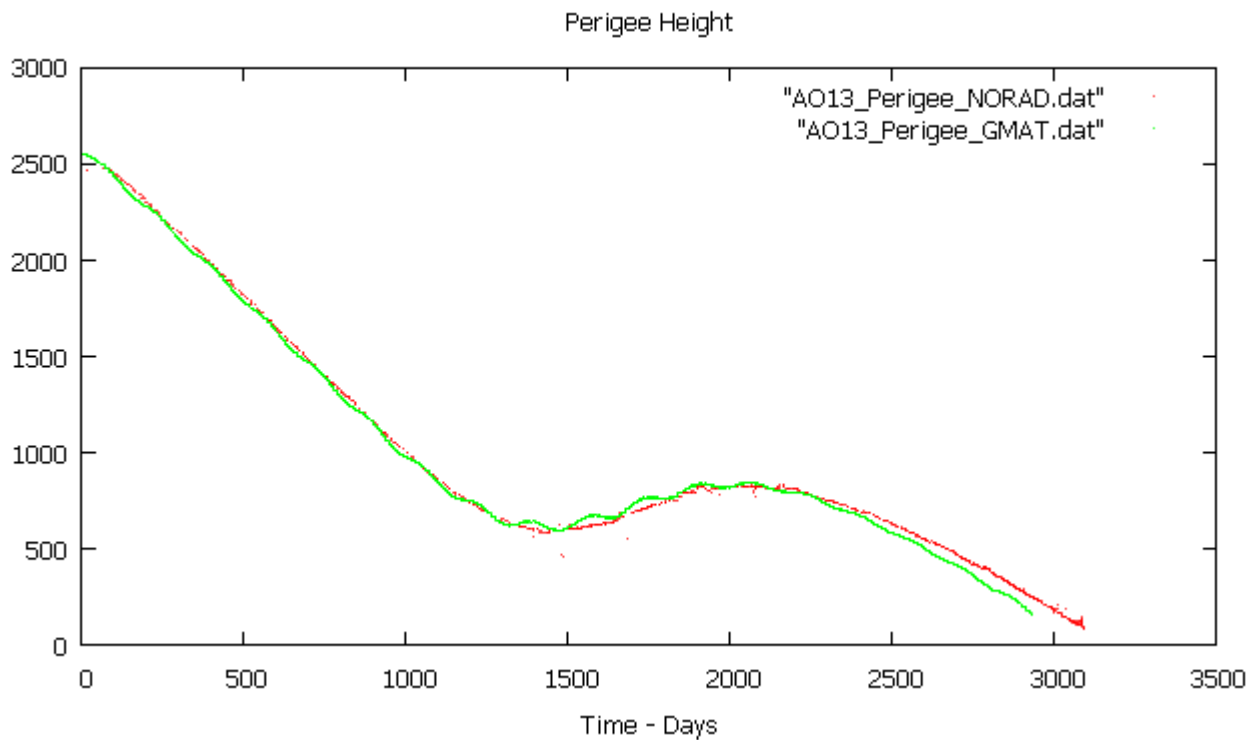


Figure 2: AO-13 perigee height as calculated by GMAT plotted with NORAD tracking data.

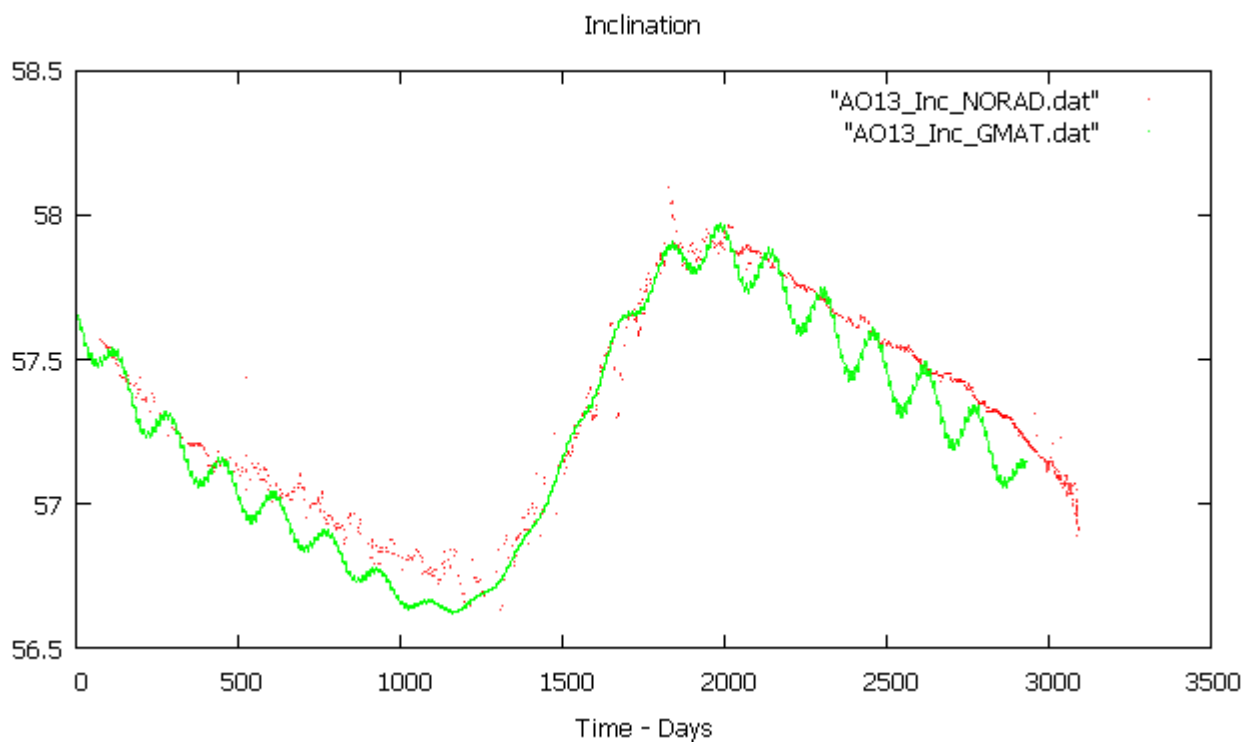


Figure 3: AO-13 inclination as calculated by GMAT plotted with NORAD tracking data.

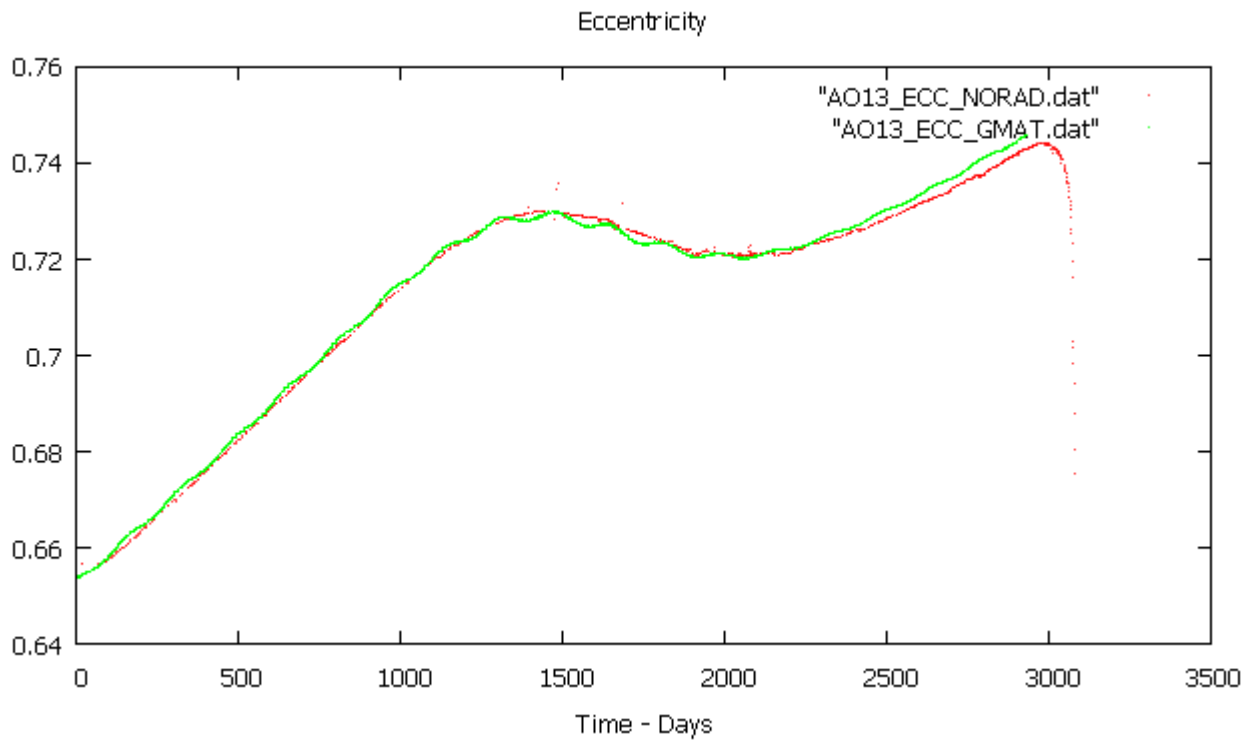


Figure 4: AO-13 eccentricity as calculated by GMAT plotted with NORAD tracking data.

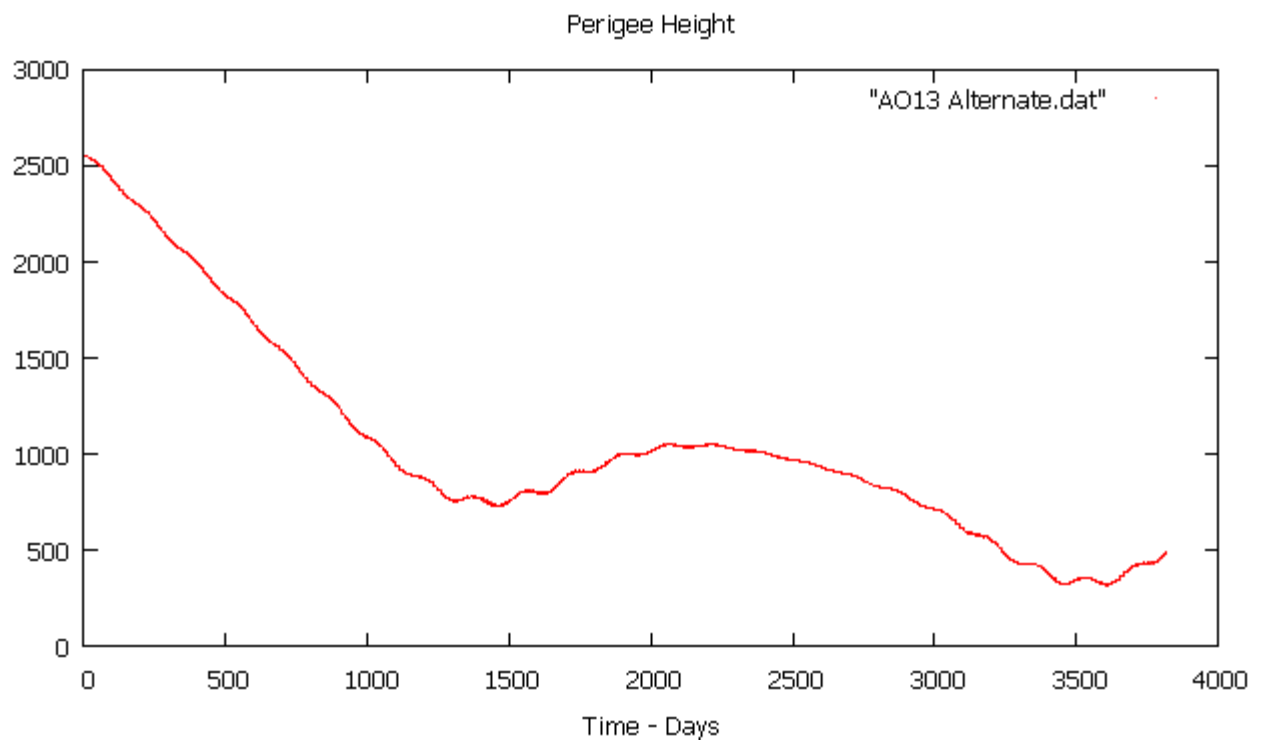


Figure 5: If the initial Right Ascension of Ascending Node had been 15 degrees less, AO-13 perigee height would have remained above 400 km throughout 1998

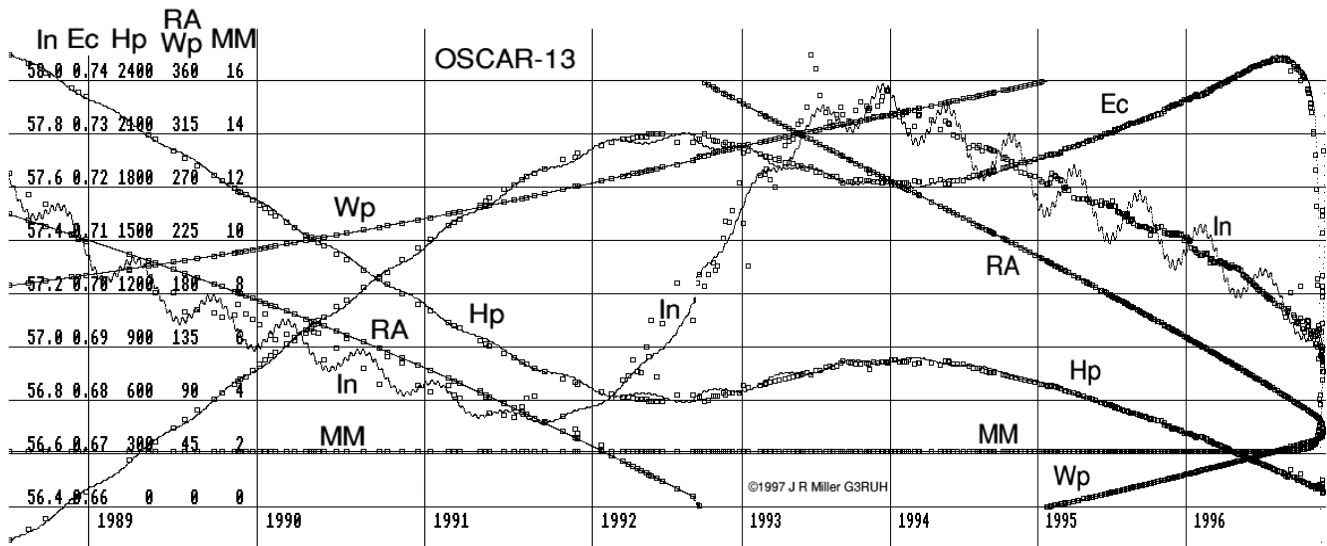


Fig 6: Calculated results from James Miller G3RUH's Integrator program as published in Ref (3)
Used by permission of James Miller G3RUH

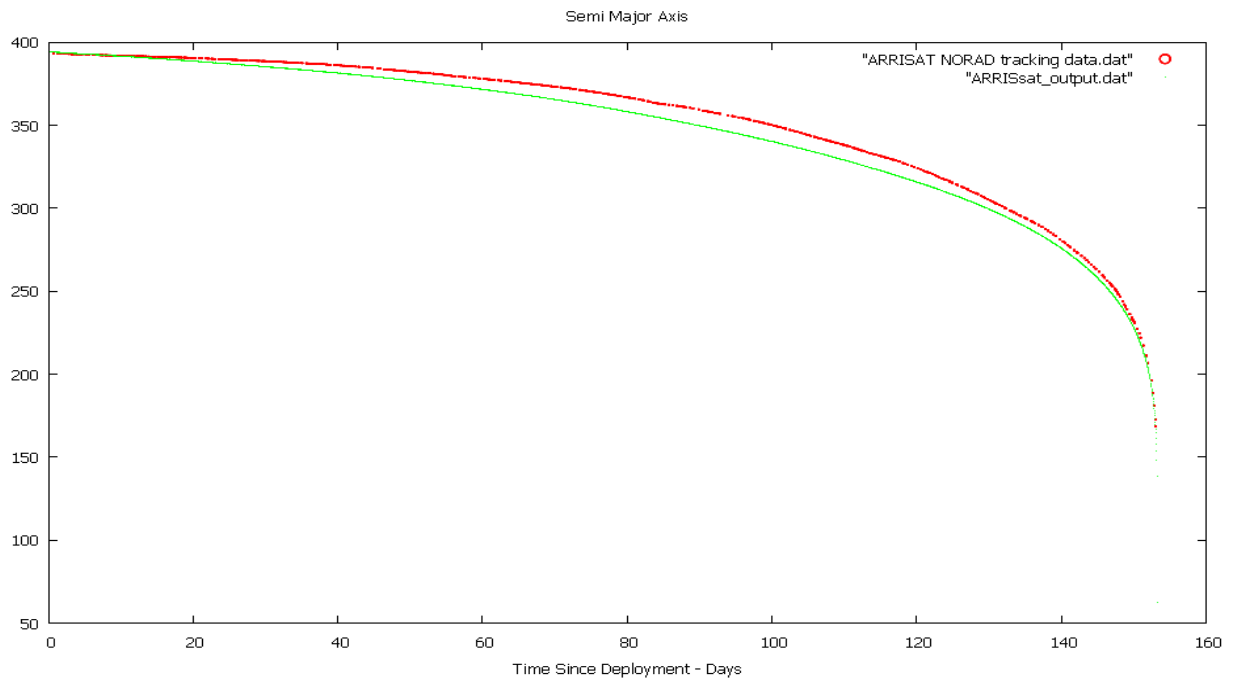


Figure 7: ARISsat-1 altitude as calculated by GMAT plotted with NORAD tracking data

%General Mission Analysis Tool(GMAT) Script for ARRISsat - Created: 2012-09-27

%----- Spacecraft

```
Create Spacecraft ARRISsat;
GMAT ARRISsat.DateFormat = UTCGregorian;
GMAT ARRISsat.Epoch = '04 Aug 2011 18:02:17.063';
GMAT ARRISsat.CoordinateSystem = EarthMJ2000Eq;
GMAT ARRISsat.DisplayStateType = Keplerian;
GMAT ARRISsat.SMA = 6765.22041221;
GMAT ARRISsat.ECC = 0.00118166;
GMAT ARRISsat.INC = 51.64136;
GMAT ARRISsat.RAAN = 276.8213;
GMAT ARRISsat.AOP = 43.5724;
GMAT ARRISsat.TA = 316.6246;
GMAT ARRISsat.DryMass = 30;
GMAT ARRISsat.Cd = 0.70;
GMAT ARRISsat.Cr = 0.70;
GMAT ARRISsat.DragArea = 0.3;
GMAT ARRISsat.SRPArea = 0.3;
GMAT ARRISsat.NAIFId = -123456789;
GMAT ARRISsat.NAIFIdReferenceFrame = -123456789;
GMAT ARRISsat.Id = 'ARRISat-1';
GMAT ARRISsat.Attitude = CoordinateSystemFixed;
GMAT ARRISsat.ModelFile = '../data/vehicle/models/aura.3ds';
GMAT ARRISsat.ModelOffsetX = 0;
GMAT ARRISsat.ModelOffsetY = 0;
GMAT ARRISsat.ModelOffsetZ = 0;
GMAT ARRISsat.ModelRotationX = 0;
GMAT ARRISsat.ModelRotationY = 0;
GMAT ARRISsat.ModelRotationZ = 0;
GMAT ARRISsat.ModelScale = 3;
GMAT ARRISsat.AttitudeDisplayStateType = 'Quaternion';
GMAT ARRISsat.AttitudeRateDisplayStateType = 'AngularVelocity';
GMAT ARRISsat.AttitudeCoordinateSystem = 'EarthMJ2000Eq';
GMAT ARRISsat.Q1 = 0;
GMAT ARRISsat.Q2 = 0;
GMAT ARRISsat.Q3 = 0;
GMAT ARRISsat.Q4 = 1;
GMAT ARRISsat.EulerAngleSequence = '321';
GMAT ARRISsat.AngularVelocityX = 0;
GMAT ARRISsat.AngularVelocityY = 0;
GMAT ARRISsat.AngularVelocityZ = 0;
```

%----- ForceModels

```
Create ForceModel LEOprop_ForceModel;
GMAT LEOprop_ForceModel.CentralBody = Earth;
GMAT LEOprop_ForceModel.PrimaryBodies = {Earth};
GMAT LEOprop_ForceModel.PointMasses = {Luna, Sun};
GMAT LEOprop_ForceModel.SRP = On;
GMAT LEOprop_ForceModel.RelativisticCorrection = Off;
GMAT LEOprop_ForceModel.ErrorControl = RSSStep;
GMAT LEOprop_ForceModel.GravityField.Earth.Degree = 4;
GMAT LEOprop_ForceModel.GravityField.Earth.Order = 4;
GMAT LEOprop_ForceModel.GravityField.Earth.PotentialFile = 'JGM2.cof';
GMAT LEOprop_ForceModel.GravityField.Earth.EarthTideModel = 'None';
GMAT LEOprop_ForceModel.SRP.Flux = 1367;
GMAT LEOprop_ForceModel.SRP.Nominal_Sun = 149597870.691;
GMAT LEOprop_ForceModel.Drag.AtmosphereModel = JacchiaRoberts;
GMAT LEOprop_ForceModel.Drag.F107 = 150;
GMAT LEOprop_ForceModel.Drag.F107A = 150;
GMAT LEOprop_ForceModel.Drag.MagneticIndex = 3;
GMAT LEOprop_ForceModel.Drag.AtmosphereModel = JacchiaRoberts;
GMAT LEOprop_ForceModel.Drag.F107 = 150;
GMAT LEOprop_ForceModel.Drag.F107A = 150;
GMAT LEOprop_ForceModel.Drag.MagneticIndex = 3;
```

%----- Propagators

```
Create Propagator LEOprop;
GMAT LEOprop.FM = LEOprop_ForceModel;
GMAT LEOprop.Type = RungeKutta89;
GMAT LEOprop.InitialStepSize = 60;
GMAT LEOprop.Accuracy = 9.999999999999999e-012;
GMAT LEOprop.MinStep = 0.001;
GMAT LEOprop.MaxStep = 600;
GMAT LEOprop.MaxStepAttempts = 50;
```

```

GMAT LEOprop.StopIfAccuracyIsViolated = true;

%----- Solvers
Create DifferentialCorrector DC;
GMAT DC.ShowProgress = true;
GMAT DC.ReportStyle = Normal;
GMAT DC.ReportFile = 'DifferentialCorrectorDC1.data';
GMAT DC.MaximumIterations = 25;
GMAT DC.DerivativeMethod = ForwardDifference;

Create Variable I DAY PERIGEE;

%----- Subscribers
Create OrbitView DefaultOrbitView;
GMAT DefaultOrbitView.SolverIterations = Current;
GMAT DefaultOrbitView.UpperLeft = [ 0.3733075435203095 0.004672897196261682 ];
GMAT DefaultOrbitView.Size = [ 0.5957446808510638 0.4330218068535826 ];
GMAT DefaultOrbitView.RelativeZOrder = 370;
GMAT DefaultOrbitView.Add = {ARRISSat, Earth};
GMAT DefaultOrbitView.CoordinateSystem = EarthMJ2000Eq;
GMAT DefaultOrbitView.DrawObject = [ true true ];
GMAT DefaultOrbitView.OrbitColor = [ 255 32768 ];
GMAT DefaultOrbitView.TargetColor = [ 8421440 0 ];
GMAT DefaultOrbitView.DataCollectFrequency = 1;
GMAT DefaultOrbitView.UpdatePlotFrequency = 50;
GMAT DefaultOrbitView.NumPointsToRedraw = 0;
GMAT DefaultOrbitView.ShowPlot = true;
GMAT DefaultOrbitView.ViewPointReference = Earth;
GMAT DefaultOrbitView.ViewPointVector = [ 30000 0 0 ];
GMAT DefaultOrbitView.ViewDirection = Earth;
GMAT DefaultOrbitView.ViewScaleFactor = 1;
GMAT DefaultOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq;
GMAT DefaultOrbitView.ViewUpAxis = Z;
GMAT DefaultOrbitView.CelestialPlane = Off;
GMAT DefaultOrbitView.XYPlane = On;
GMAT DefaultOrbitView.WireFrame = Off;
GMAT DefaultOrbitView.Axes = On;
GMAT DefaultOrbitView.Grid = Off;
GMAT DefaultOrbitView.SunLine = Off;
GMAT DefaultOrbitView.UseInitialView = On;
GMAT DefaultOrbitView.StarCount = 7000;
GMAT DefaultOrbitView.EnableStars = On;
GMAT DefaultOrbitView.EnableConstellations = On;

Create XYPlot XYPlot1;
GMAT XYPlot1.SolverIterations = Current;
GMAT XYPlot1.UpperLeft = [ 0.3762088974854932 0.4439252336448598 ];
GMAT XYPlot1.Size = [ 0.5957446808510638 0.4361370716510903 ];
GMAT XYPlot1.RelativeZOrder = 368;
GMAT XYPlot1.XVariable = ARRISSat.A1ModJulian;
GMAT XYPlot1.YVariables = {ARRISSat.Earth.Altitude};
GMAT XYPlot1.ShowGrid = true;
GMAT XYPlot1.ShowPlot = true;

Create ReportFile ReportFile1;
GMAT ReportFile1.SolverIterations = Current;
GMAT ReportFile1.UpperLeft = [ 0 0 ];
GMAT ReportFile1.Size = [ 0.5997458703939009 0.8 ];
GMAT ReportFile1.RelativeZOrder = 498;
GMAT ReportFile1.Filename = 'ARRISSat_output.txt';
GMAT ReportFile1.Precision = 8;
GMAT ReportFile1.WriteHeaders = On;
GMAT ReportFile1.LeftJustify = On;
GMAT ReportFile1.ZeroFill = Off;
GMAT ReportFile1.ColumnWidth = 10;
GMAT ReportFile1.WriteReport = true;

%----- Mission Sequence
BeginMissionSequence;
For I = 1:1:5000; %simulate up to 5000 orbits, stop each run at equator crossing
    Propagate LEOprop(ARRISSat) {ARRISSat.Earth.Latitude = 0.0};
    GMAT DAY = ARRISSat.UTCModJulian - 25778;
    GMAT PERIGEE = ARRISSat.Earth.SMA - 6371;
    Report ReportFile1 DAY PERIGEE;
EndFor;

```

FUNCube from AMSAT-UK Launch and Early Operations

David Bowman G0MRF

FUNCube-1 is a 1U CubeSat project from AMSAT-UK. It carries an amateur radio linear transponder and provides educational outreach directly to the classroom via its telemetry and the project's groundstation receiver, The FUNCube dongle. It is due for launch in the first quarter of 2013 from Yasny in Russia; this paper gives an overview of the satellite functions and looks at the launch and early operations designed to bring the CubeSat safely into nominal operation.

Concept

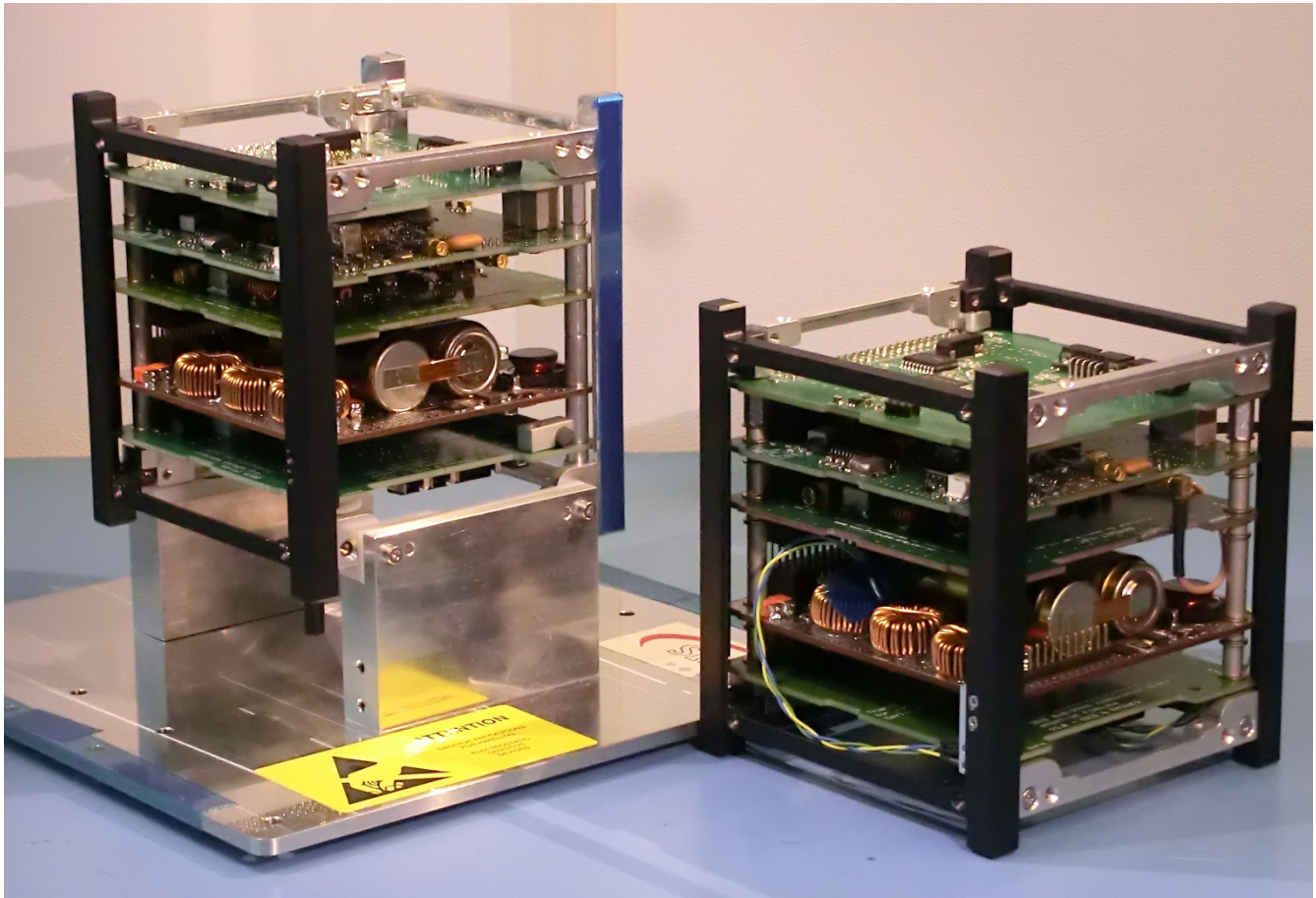
Educational outreach is generally understood to be a fundamental requirement of amateur radio satellite launches. While amateur radio has always been a hobby in which the self training of the licensee is an important benefit to the participants, in recent years, the ability of AMSAT groups to provide on orbit educational resources which actively promote the study of Science Technology Engineering and Math subjects, otherwise known as STEM, has allowed some financial support for placing satellites in orbit. FUNCube in the UK and Fox in the USA have both received funding to promote educational outreach which will hopefully bring space education to students as well as members to AMSAT.

Status

The flight model FUNCube-1 satellite (1) is currently nearing the completion of its assembly integration and verification (AIV) phase. At present the satellite is located at our commercial partners ISIS, Innovative Solutions in Space, at Delft in the Netherlands (2) and is undergoing testing of the subsystems and calibration of the telemetry sensors. In early November the assembled and tested satellite will undergo thermal vacuum and vibration acceptance testing before being loaded, with two other CubeSats into a 3U CubeSat deployer before being shipped to the launch site at Yasny. The hardware used for FUNCube-1 is a combination of commercially available space products which includes the structure, antenna deployment system and the electrical power system. Other PCBs with a project specific function have been developed within AMSAT-UK and AMSAT-NL. These include the UV linear transponder and command receiver. Also the command control and telemetry board (CCT) which controls the satellite and gathers and formats the telemetry and a board dedicated to the 2m final amplifier.

A second set of the 3 'AMSAT' PCBs described above and known as FUNCube-2 within the group, has been delivered to the UKube project. This 3U satellite project is sponsored by the UK Space Agency and managed by the Scottish company ClydeSpace (3). UKube-1 is scheduled for launch on a Soyuz-2 launcher in March 2013. It is particularly pleasing to AMSAT-UK that they have recognised the educational outreach value of the project and based on that, have provided a 'free to AMSAT' route into space for a second FUNCube system.

FUNCube -1 Flight model (left) and engineering model in the ISIS lab.
Sept 2012



Overview of the FUNCube satellite.

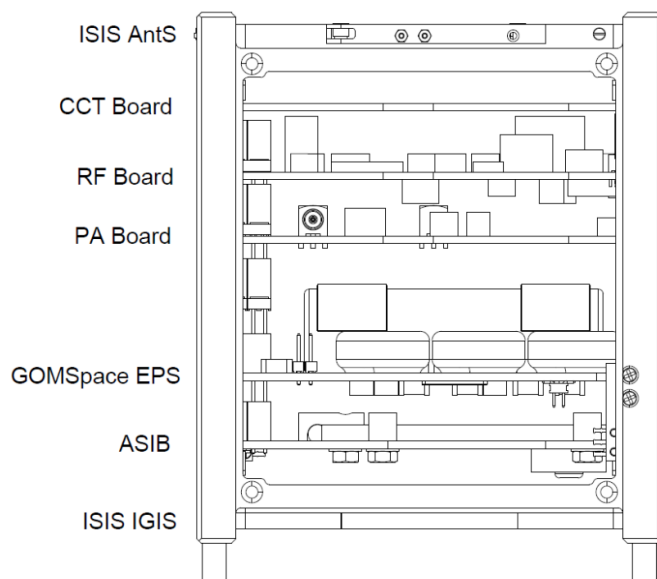
Telemetry: The educational outreach of FUNCube is based on the telemetry generated and transmitted by the satellite and on the 9 banks of 200 character text messages which will be used to transmit greetings messages along with data from the satellite subsystems. Telemetry is gathered from the sensors and is transmitted on 145.935MHz using BPSK with a bit rate of 1200 BPS. The BPSK format is based largely on the successful forward error correcting code implemented by Phil Karn and used on AO-40; it includes both convolutional coding and interleaving to deliver a robust error detecting system. Each frame consists of a 2 bit satellite id and a 6 bit frame type indicator then 440 bits of real time data followed by 1600 bits of payload data. The 256 byte (2048 bit) data frame, once it has passed through a pair of RS(160,128) encoders, the scrambler, the convolution encoder and the interleaver, has 5200 bits to transmit. Thus, each data frame, at 1200BPS, will take 4.3s to transmit. Between each data frame a burst of tones are transmitted for 700mS. This assists the ground station decoder to lock onto the signal; it also makes the signal very easy to identify and results in a total time of 5 seconds for each frame of data. There is a total of 24 frames transmitted This equates to an overall time of $24 \times 5 = 120$ seconds to transmit all the data.

Telemetry is divided into 3 different types:

Real time telemetry. This data is collected and transmitted in near real time. RTT comprises 55 channels of which 36 are analogue values. Additionally, there are 15 status channels represented by a zero or one, while the remainder are 2 or 3 bit values that define an operating mode within a subsystem. The causes of delay are, as a result of the collection process, temporary storage in memory and the application of forward error correction. The max delay from sample to transmission is 10 seconds.

Whole orbit data. From the real time telemetry, 10 channels have been selected to give an overview of an orbit of FUNcube. These 10 channels are sampled once every minute and stored so that 104 samples can be transmitted as whole orbit data. Four additional channels, not available in real time, are used for the MSE experiment. – see below. The 104 x 14 stored samples can each be displayed in graphical form on the ‘Dashboard’ software from AMSAT-UK. It will also be possible to extract this data in CSV format for later analysis.

The Material Science Experiment (MSE) is essentially a space-based version of the classic Leslie’s Cube physics experiment which examines the energy radiated by a material based on its colour. FUNcube-1 has two metal bars on the external surface of +X solar panels. One bar is brightly polished Aluminium, while the other is anodized matt black. These are thermally isolated from the structure. They will absorb energy during the illuminated period of the orbit and will radiate energy from the moment the satellite enters eclipse. In addition to the two bars mounted on the solar panels, the structure of the CubeSat has also been produced with natural silver aluminium and black anodised finishes. This acts as a back- up, should the solar panel mounted bars or their thermistors fail.



Internal layout of PCBs within FUNcube.

Frame Type	Frame Id	Frame type
RTT + Whole Orbit	WO1	01
RTT + Whole Orbit	WO2	02
RTT + Whole Orbit	WO3	03
RTT + Whole Orbit	WO4	04
RTT + Whole Orbit	WO5	05
RTT + Whole Orbit	WO6	06
RTT + Whole Orbit	WO7	07
RTT + Whole Orbit	WO8	08
RTT + Whole Orbit	WO9	09
RTT + Whole Orbit	WO10	10
RTT + Whole Orbit	WO11	11
RTT + Whole Orbit	WO12	12
RTT + High Resolution	HR1	13
RTT + Fitter Message	FM1	14
RTT + Fitter Message	FM2	15
RTT + Fitter Message	FM3	16
RTT + High Resolution	HR2	17
RTT + Fitter Message	FM4	18
RTT + Fitter Message	FM5	19
RTT + Fitter Message	FM6	20
RTT + High Resolution	HR3	21
RTT + Fitter Message	FM7	22
RTT + Fitter Message	FM8	23
RTT + Fitter Message	FM9	24

Telemetry transmission sequence. 120 seconds

High resolution data. The final type of telemetry available is generated from 14 sensors which include sun and temperature sensors mounted on 5 of the 6 solar panels. Although referred to as ‘hi-res’, these sensors are sampled at 1 second intervals for a total of 60 seconds. It is hoped that the data produced will provide a method of determining spin rate and solar panel functionality. These data can also be displayed graphically via the AMSAT-UK software. Also sampled is bus voltage. While the readings will be static during the early life of FUNcube, this data will become very interesting as the battery begins to fail.

Amateur radio transponder.

Unlike many other “Amateur Radio CubeSats”, FUNcube provides a 2- way communications capability. The linear transponder operates in mode UV, i.e. 70cm uplink and 2m downlink. It is inverting, and 19kHz wide to the -3dB points. When operating in this mode, the total RF output from the satellite is 400mW or +26dBm PEP, which normally includes low power telemetry at around 50mW. The transponder has an AGC range of 43dB.

Uplink passband centre	435.140 MHz	Transponder uplink:	435.150 to 435.130
Downlink passband centre	145.960 MHz	Transponder downlink	145.950 to 145.970
Telemetry beacon	145.935 MHz		

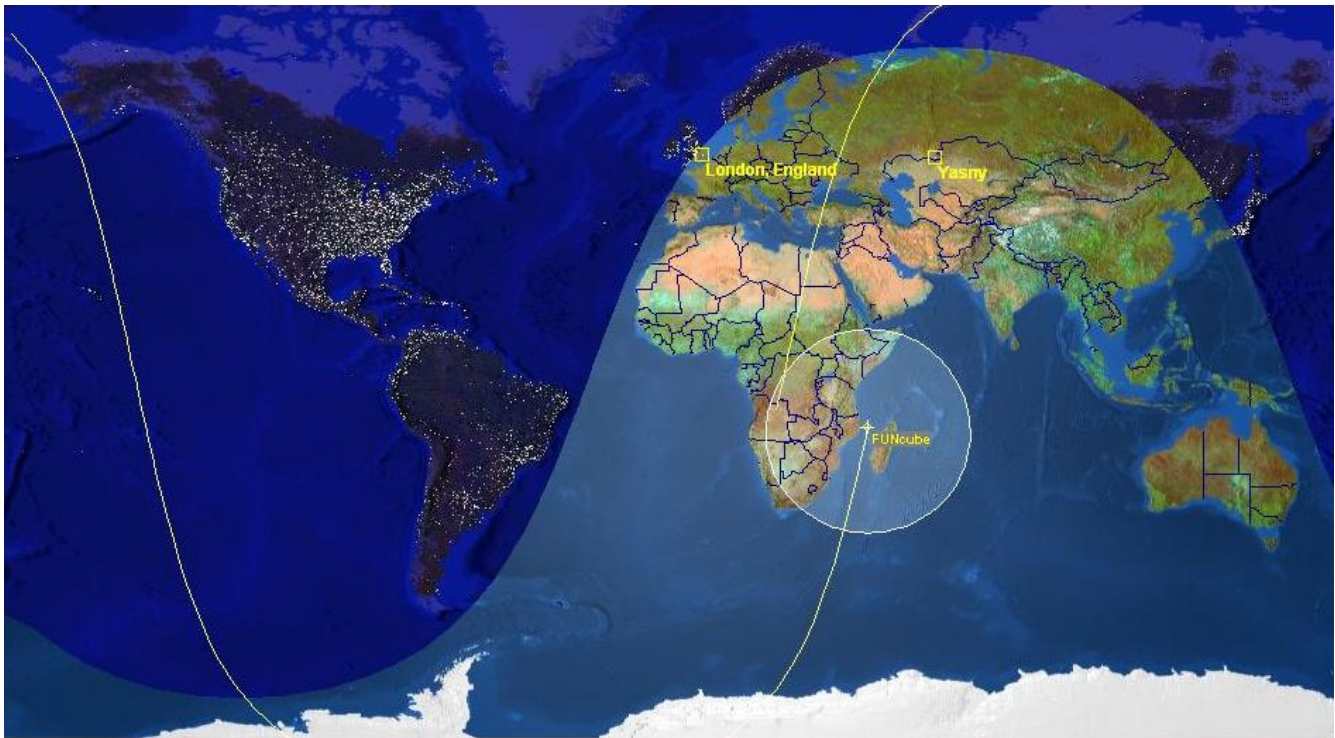
Launch sequence and the first orbit

FUNcube will be launched in the early part of 2013 on-board a Dnepr launch vehicle from Yasny in Russia. The Dnepr (4) is a converted SS-18 Intercontinental ballistic missile and is launched from a heavily reinforced underground silo. The method of launch is somewhat dramatic and will certainly give our team members their own ‘several seconds of terror’ as the Dnepr is ejected from its silo by a mixture of compressed steam and blackpowder. As it hangs passively in mid-air, several metres clear of the silo, the engines ignite and, hopefully, the vehicle accelerates away to the south west, heading over Kazakhstan, towards orbit above the Indian Ocean. Our control over the fate of FUNcube-1 during launch is already sealed. It is the project management, the design and peer review process, appropriate construction and vigorous testing that will decide if the satellite will survive the 11 minute ride to orbit. Having reached orbit at 700km the primary payload, DubaiSat-2, will be separated into a sun synchronous orbit. The upper stage will make a small manoeuvre before the secondary payloads (19 at the time of writing) are deployed. At launch + 15 minutes and 20 sec FUNcube-1 is released from its pod. Microswitches in the base of the structure connect power to the satellite and initiate a 5 minute timer.

At launch +20 mins 20 sec, the satellite should be safely clear of the other payloads and the on-board computer begins a sequence of actions that checks the health of the battery and sends commands via an I2C bus to deploy the 435MHZ and then the 145MHz antennas. Within a few seconds, the satellite

switches on the command receiver and begins to operate in 'safe mode', collecting data from its sensors and transmitting low power telemetry on 145.935MHz.

In safe mode the transponder is off and FUNcube-1 will transmit telemetry from its dipole antenna at 50mW. The mode is highly power positive. Tests during integration show that the satellite with a battery voltage of 7.8Volts consumes less than 500mW in this mode. This compares to the ability of the solar panels to generate an average of 3.2 Watts during the illuminated part of the orbit. The screenshot from NOVA below shows the approximate position of FUNcube-1 at the time the transmitter activates. The image also shows that the next 75 minutes is spent passing over Oceans and some of the least densely populated regions of the planet. Clearly, collecting real time telemetry during this critical period is going to be challenging.



Predicted first orbit of FUNcube based on altitude 690km, inclination 98.2 degrees.

Bringing a CubeSat into nominal operation is not a trivial matter. The record of educational launches is poor, with fewer than 50 percent operating as intended one week after launch. Some fail to activate when deployed, presumably due to vibration damage or insufficient vacuum testing. A surprising number fail within a few orbits due to power charging or battery issues, while others have spun uncontrollably. Becoming entangled either physically or magnetically with other satellites is not unheard of, while other problems include solar arrays connected incorrectly, not being able to receive commands, non-deployment of antennas and, on the odd occasion, when the onboard computer decides to have a nervous breakdown and the operators wish they had included a reset command instead of having to drain the batteries.

A few days searching the internet can produce an impressive list of vital lessons learned. All we can do is look at the misfortunes of others and ensure that the project management, peer review process and pre-flight testing avoid some of the obvious pitfalls but also produces plans for the unexpected.

Early operations

For FUNcube, we would like to receive telemetry data prior to the first pass over Europe at launch plus 97 minutes. We are actively seeking operators in Southern Africa, the Hawaiian Islands and Alaska to assist with forwarding telemetry via the internet to the Mission Control in the UK. Whilst we anticipate everything working to plan, we have discussed numerous failure scenarios and continue to work on a flow chart to aid the decision-making process and to define appropriate actions or methods of mitigation. To give just one example, an analysis of the Lithium ion batteries suggest that if launched with a reasonable state of charge, with a nominal deployment of the antennas, but with no power from the solar arrays, we will have power for around 12 hours of safe mode operation. Even this unthinkable situation has many possible responses. Do you listen to your satellite for 12hrs sending telemetry? Do you switch on the transponder for a few hours? Or would a better response be, to turn the telemetry off, which saves a lot of power, and then turn the transponder or telemetry on over populated areas maximising the opportunity for amateurs to use it. Clearly a plan is required.

During the first few orbits tasks include:

- 1) Ensure the antennas have deployed
- 2) Confirm all of the solar panels are producing power
- 3) Check the battery is being charged and is within temperature limits
- 4) Determine the spin rate and change in rate over time
- 5) Examine the temperature extremes in sunlight and eclipse
- 6) Recover the whole orbit data collected since the initial activation of the satellite
- 7) Confirm the command receiver characteristics and check the cmd decoder is operating
- 8) Compare the telemetry with that obtained from prelaunch testing
- 9) Keep the community informed of progress

In the next few days

- 1) Upload a series of commands to check the satellite's modes
- 2) Increase the transmitter power during a pass or between command stations and check the effect on temperatures and power drain
- 3) Use whole orbit data to ensure the percentage drain on the battery in eclipse is within limits
- 4) Find out which object number we are!
- 5) Check autonomous mode switching between sunlight and eclipse functions as intended
- 6) Test upload a 200 character message to one of the 9 message memories
- 7) Test the communications system for EMI and performance verification
- 8) Begin to refine the set point data used to place the satellite in safe mode
- 9) Keep the community informed of progress

And finally....Open up FUNcube-1 for normal operations. High power telemetry in day light for educational outreach, Transponder in Eclipse. Mon-Fri. Transponder 24hrs on weekends. (Provisional)

During the design and construction of FUNcube the team have prioritised reliability and failure mitigation.

Battery failure: Although we have calculated that the depth of discharge at the end of eclipse should only be 6%, the battery will eventually fail and we have designed the system to operate in sunlight only. When this happens, we have ensured that there is a 10 second delay as the satellite passes from eclipse into full sunlight. This prevents software failure in the 5-8 seconds transition time between eclipse and full sunlight that is a characteristic of our orbit.

Quality standard: All PCBs on the flight models have been assembled externally by personnel trained to ESA standards. We have also vibration-tested the engineering models to levels in excess of those specified for launch on several different launch vehicles.

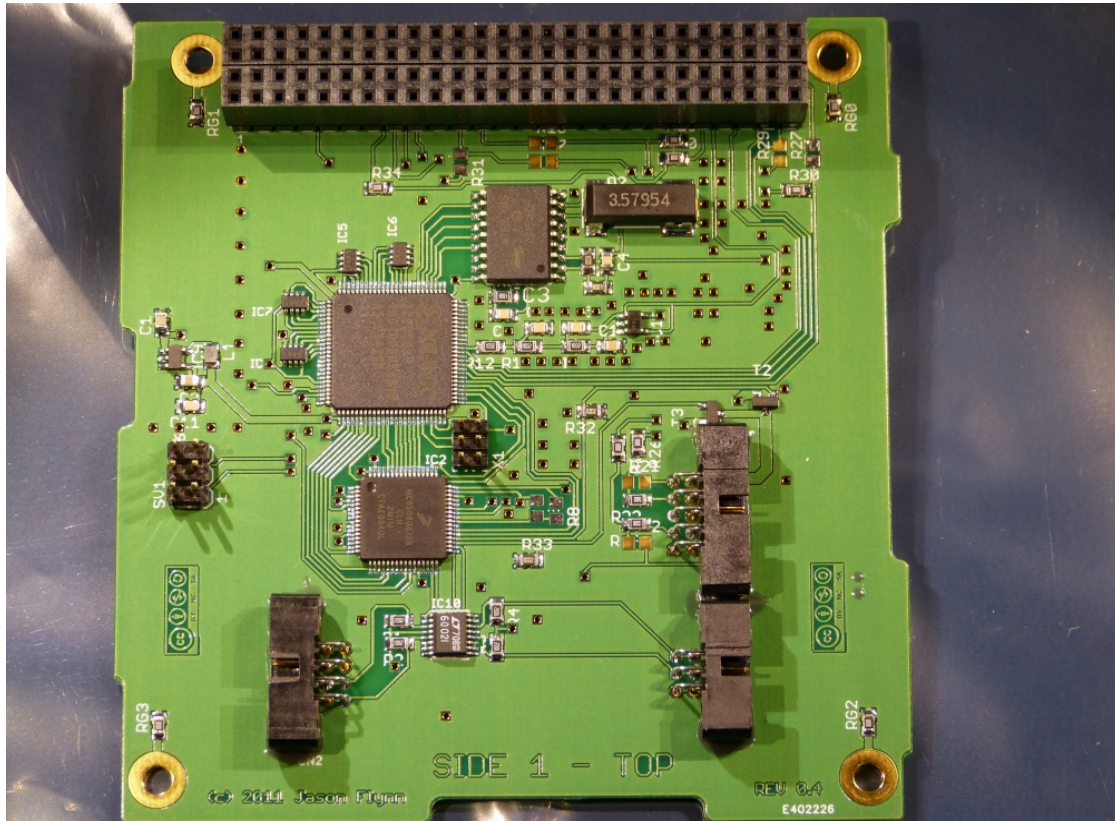
Radiation: We are launching into low earth orbit but at the peak of the sunspot cycle. To mitigate against radiation failure we have used solar panels with cells mounted onto Aluminium to increase the protection to the spacecraft electronics. Also to protect against failure of the Micro controller, we have implemented a command decoder in hardware. The decoding and mode control resides in a Xilinx XC2C128 CPLD which has greater resistance to total radiation dose. Should the microcontroller fail, we lose telemetry but retain the ability to change operating mode from 'transponder' to FM – DSB or to receive only.

Power budget: A 1U CubeSat has a very limited power capability. FUNcube-1 is designed to be power positive in all modes in sunlight. This prevents a situation common in CubeSat design where signals are produced at high power over short periods with 'recharge time' between transmissions. This method is fine while you have battery power, but it is a mission critical decision. With no battery, the drain on the solar panels is too high to allow the transmission. The spacecraft dies. The FUNcube design includes a power efficient CCT board that consumes just 33mW peak and an average of 15mW from a 3.3V supply. The RF board makes extensive use of operational amplifiers at 10.7MHz and 145MHz. These offer a substantial power saving over the popular class A monolithic 50 ohm gain blocks.

Conclusion

In 2013 FUNcube-1 and UKube-1 will be launched into low Earth orbit. Financial support for the construction of FUNcube and the launch of UKube has been forthcoming because of the educational outreach that has led both projects. The involvement of AMSAT has allowed transponders to be included in both spacecraft and has produced a design in FUNcube which should not see operational

service limited by the lifetime of battery. We hope the collaboration between academia and AMSAT will continue and that the members of both groups will support future, more ambitious missions.



Command Control and Telemetry board with Xilinx CPLD and Freescale MCU

References

- 1 <http://funcube.org.uk/>
- 2 <http://www.isispace.nl/cms/>
- 3 <http://www.clyde-space.com/>
- 4 http://www.kosmotras.ru/en/rn_dnepr/

The Fox Sniffer – A low cost, low power GPS for Small Satellites

Tom Clark, K3IO (k3io@amsat.org)

In the wild, the Fox makes his living by hunting small prey. In his arsenal of hunting tools the Fox, like all his canine brethren, makes use of a very sensitive sense of smell.

His nose has a sensitivity $\sim 10^4$ - 10^5 :1 compared to a human for certain scents related to food and survival. With this SSP (Sniff Signal Processing) he can tell the difference between a coyote and a badger, a rat and a tasty field mouse, a farmer's turkey and a turkey vulture and occasionally even one of Aunt Enna's punkin pies left to cool on the window sill.



As a spin-off from AMSAT's FOX development, I've been thinking about the design of a small (single 10x10cm PCB) GPS with < 100mW power. The concept assumes we also have developed "smart" telemetry links in the 10-100 kb/sec range (no 1200 baud AX.25!!) using the SDX; this will also draw heavily on ideas that were developed for ARISSat-1 by KA9Q.

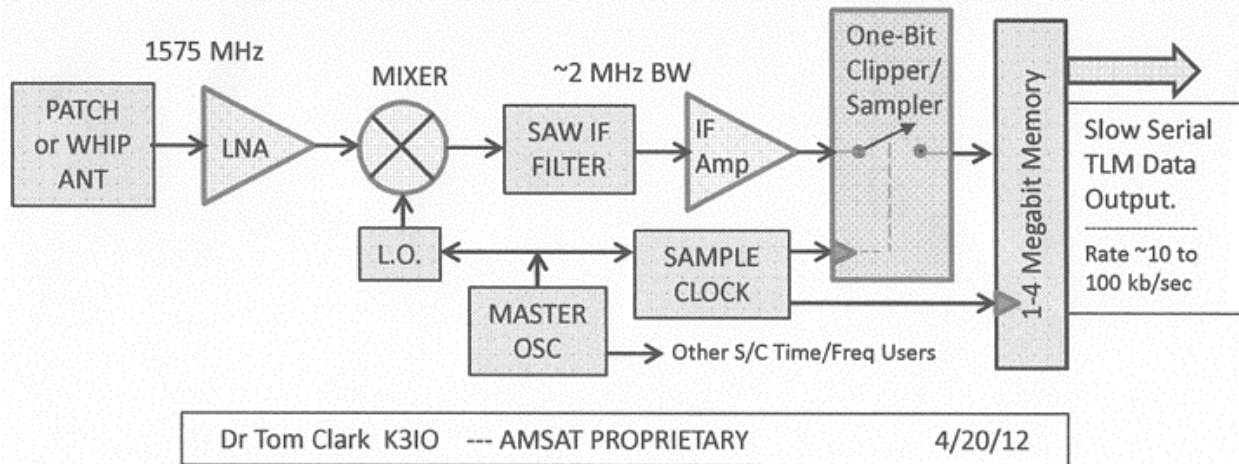
The spacecraft GPS will consist of an analog RFIC front end, ~1 MB of RAM. A time tagged sample of the 2 MHz wide GPS (and Galileo) C/A code signals at 1575.42 MHz will be written to RAM, and then "trickled" down to the ground for signal processing.

In conventional GPS board-level receivers, the RF data acquisition plus and the microprocessor used for signal processing add up to a watt or more of power. By flying only the RFIC and the small RAM memory, the power consumption drops to under 100 mW.

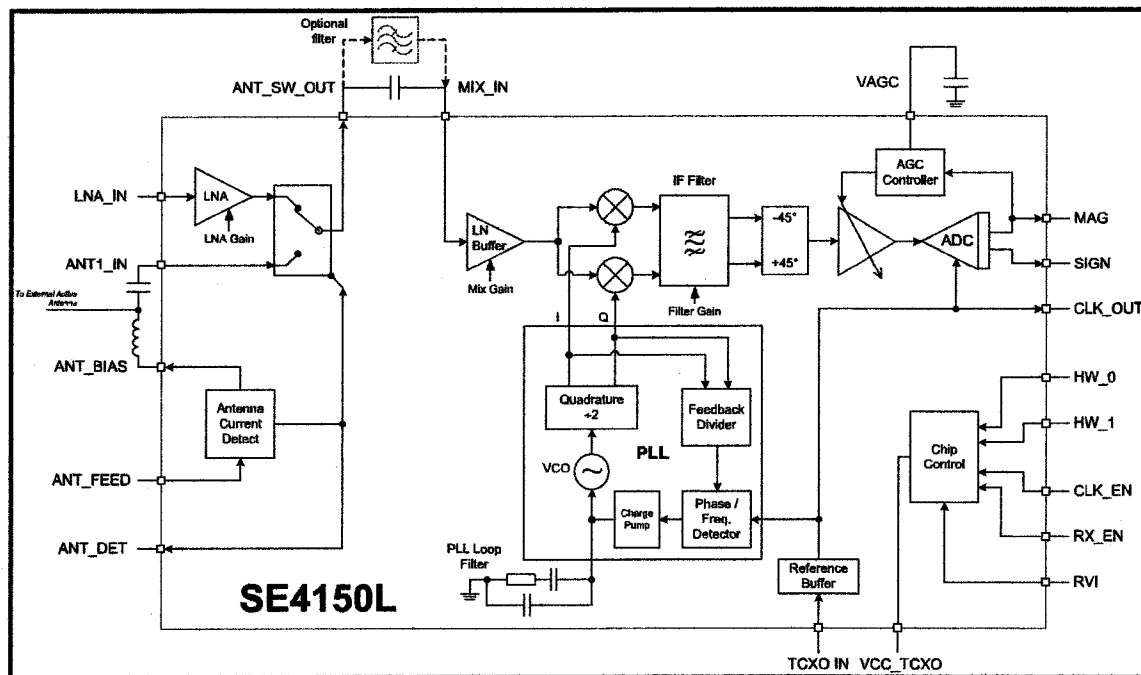
The GPS signal post-processing on the ground will allow much more detail to be extracted from the signals. If two Cubesats are flying near each other, the vector separation between them can be determined with only a couple of seconds "sniffs". This would be very useful in resolving the perennial "Which set of NORAD Keps go with which satellite?" question.

I came up with the "sniffer" concept last April when we were preparing the AMSAT portion of one of the NASA/EDISON proposals. Here was the idea I presented:

SAMPLING GPS RECEIVER CONCEPT



After I presented this idea, I found the Skyworks SE4150L "GPS RFIC on a chip" (\$3.00 from DigiKey – see <http://www.skyworksinc.com/Product.aspx?ProductID=987>) which is a very! close match to the Fox Sniffer requirements:



In the presentation at the AMSAT Symposium I'll discuss the digital part of the Sniffer board, telemetry rates formatting, and ground-based signal processing.

The Future of CubeSat Communications: Transitioning Away from Amateur Radio Frequencies for High-speed Downlinks

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September 2012

Abstract

This paper explores the evolution of CubeSat communications, starting with the first CubeSat launch in 2003 and ending with the latest ELaNa-6 launch from Vandenberg AFB on 13 September 2012. The communication systems for the first few CubeSats were based on COTS amateur radio gear, which worked extremely well but had very limited data rates. With the maturation of CubeSats from beep-sats to high-performance satellites with science or military missions, cheap, high-bandwidth communication systems are being developed. This paper aims to document these new high-bandwidth systems.

1 Introduction

The CubeSat program was started in 1999 by Dr. Jordi Puig-Suari at California Polytechnic State University and Robert Twiggs at Stanford University [1]. The 10 x 10 x 10 cm form factor was loosely based on solar cell sizes and airline carry-on luggage volume. From 2003 to September 2012, 72 CubeSats were delivered to orbit, 17 CubeSats decayed or deorbited, and 19 CubeSats launched but failed to make orbit [2].

2 CubeSat Classes

The CubeSat community is large and growing. Developers building CubeSats fall into two groups: teams that are new to the CubeSat concept and are learning how to start a program and build their first satellite, and established teams that already have one or more satellites in space.

2.1 Beginner CubeSats

New CubeSat teams start with designing a basic CubeSat. This is typically done by playing a systems integrator role by assembling off-the-shelf components and subsystems. These CubeSats typically carry a simple payload, such as a small camera. The main goal of these CubeSats is student education and development of processes and procedures for building satellites. Mission lifetimes are frequently less than one year.

These so-called “beep-sats” typically use VHF or UHF amateur radio frequencies, due to existing inexpensive terrestrial hardware that can be easily repurposed for satellite use. The amateur radio service is also allocated worldwide, so satellites can autonomously beacon down data and use amateur radio operators spread across the world for both telemetry reception and satellite commanding.

The exceptions to the beginner CubeSat rule are the universities that have existing small satellite programs, such as the University of California Berkeley and the University of Colorado Boulder, and some government labs. They leverage their current processes and procedures to build their first CubeSats, with mixed results.

CP4: This 1U CubeSat was the first Cal Poly satellite to achieve orbit, on 17 April 2007. Its main payload was an energy storage and dissipation device, but the payload was never exercised on orbit. The communication system was based on a single-chip CC1000 transceiver, which worked well for transmitting but had serious receive problems. The modulation scheme was 1200-baud FSK at 437.325 MHz, which required precise tuning of an SSB receiver for decoding [3].

Libertad-1: The first satellite built in Colombia by Universidad Sergio Arboleda, this 1U CubeSat contained a StenSat transceiver. Due to funding and time constraints, this spacecraft contained no payload and only primary batteries. It beamed housekeeping data on 437.405 MHz every ten minutes in several AX.25 1200-baud frames [4].

HRBE: After several failed launch attempts, Montana State University finally launched their first 1U CubeSat on ELaNa-3 on 28 October 2011. This CubeSat also used a CC1000 transceiver, which had the same receive problem as CP4. After launch, the team traveled to SRI International to use their 18-m dish. A link was successfully established and the link deficiency was discovered empirically. The team then purchased a 1.5 kW amplifier for their primary yagi ground station [5, 6].

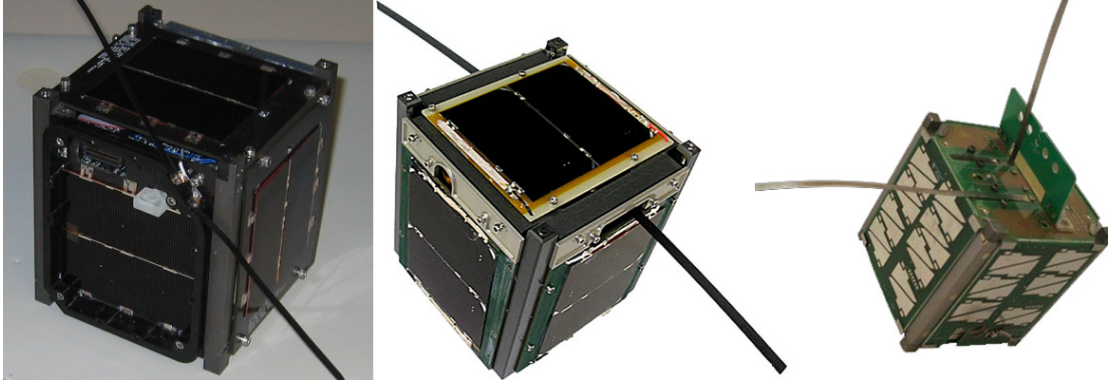


Figure 1: CP4, HRBE, and Libertad-1 CubeSats.

2.2 High-performance CubeSats

Once a CubeSat team builds a low-performance CubeSat, they gain the expertise and knowledge to build more complex spacecraft. CubeSats in this category are expensive to build, typically more than \$1 million. In the United States, only the government, through the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), or the military, has funded these high-performance CubeSats to date.

As teams transition into the high-performance CubeSat realm, they quickly realize that the 1200- or 9600-baud communications that are prevalent in the beep-sats no longer meet their data requirements. While the amateur radio satellite service does have 3 MHz of spectrum, the International Amateur Radio Union has allocated CubeSats in the spectrum between 437.100 and 437.575 MHz, with a maximum single satellite allocation of 20 kHz. This was done to protect the existing and future amateur radio voice satellites [7].

Non-amateur radio licenses prohibit autonomous beaconing of satellite data. This is a big disadvantage because the CubeSat teams can no longer rely on the existing network of amateur radio operators to downlink beacon data and forward it to the team. Non-amateur satellite licenses are usually point-to-point, so all ground stations commanding and receiving satellite data must be on US territory and must be licensed, an expensive and time-consuming process.

2.2.1 NSF CubeSat Program

The NSF CubeSat Program was started by Therese Jorgensen in 2008. The primary mission is space weather, with higher education as a secondary objective. Teams submit a science proposal, are selected by an open review process, and are funded at around \$1 million over two years to build the entire spacecraft and perform operations. NSF provides a launch for their projects [8].

To date, eight CubeSats have been selected for funding, and four have flown in space. Three of the NSF CubeSats that have flown in space are the following:

RAX: The RAX-1 spacecraft was the first NSF CubeSat launched from Kodiak, Alaska, on STP-S26 on 19 November 2010. It contained a radar receiver and looked for field-aligned irregularities induced in the aurora. Solar panel degradations caused RAX-1 to fail shortly after launch [9]. However, a backup flight spare was quickly upgraded and RAX-2 was launched on 28 October 2011 on a Delta II from Vandenberg. RAX-2 is doing well and still collecting science data 10 months after launch [10].

The RAX satellites use a AstroDev Lithium-1 radio at 9600-baud GMSK. The RAX satellites are using the amateur radio satellite service, and have pledged to

perform RF spectrum noise analysis with the radar receiver when the primary mission is done.

Additionally, the RAX satellites also have a Microhard MHX-2400 S-band transceiver on board. Unfortunately, the effective data rate is not much faster than the 9600-baud downlink with a much larger DC power draw, so that radio was only exercised for initial checkout and for keeping the batteries heated.

DICE: The science payload for these two 1.5U CubeSats required a high-data-rate downlink, much faster than any existing CubeSat has used. After extensive reading of the NTIA Red Book, the DICE team selected the 460-470 MHz Meteorological-satellite (space-to-Earth) band. Red Book footnotes impose serious power flux density limitations in this band, so a large dish is required to close the link [11].

DICE was launched on the ELaNa-3/NPP mission from Vandenberg AFB on 28 October 2011. The 18-m dish at Wallops Flight Facility was used as the primary earth station. The 18-m dish at SRI International was used as a backup, but local terrestrial interference limited its usefulness [12].

The spacecrafts flew L3 Cadet radios, which use about 3 MHz of RF bandwidth for a 1.5 Mbit/sec data throughput with heavy forward error correction. DICE is the first CubeSat to get a license through the NTIA [13].

CINEMA: This 3U CubeSat used a 1 Mbps Emheiser transmitter in the 2.2 GHz Space Research Band. UC Berkeley has extensive experience with this radio system, and already had a complete ground system for communicating with their larger small satellites. This CubeSat launched on ELaNa-6/NROL-36 from Vandenberg, California, on 13 September 2012. Its mission is to study ions, neutrals, and electrons at high ecliptic latitude [14].

Both DICE and CINEMA got their spectrum certification and frequency authorization through the NTIA, because they considered themselves a federal satellite. However, during the process, the NTIA became concerned that federal/non-federal joint projects were being submitted to the NTIA instead of the FCC [15]. While they did authorize DICE and CINEMA, they recommended that future CubeSats obtain an experimental license through the FCC [16].

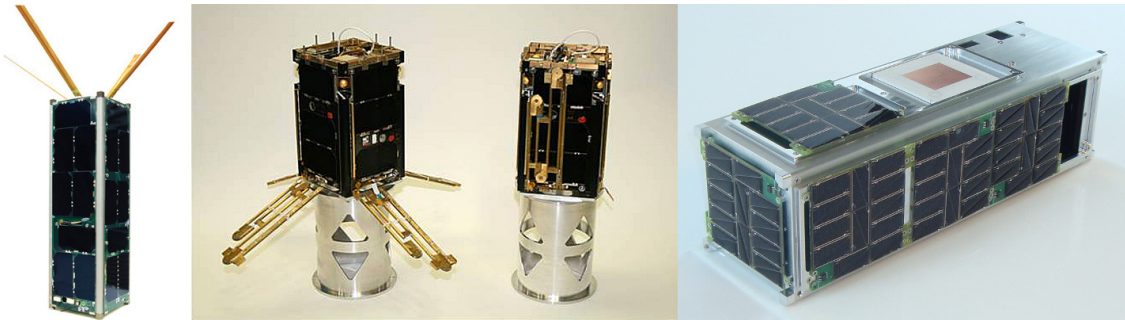


Figure 2: RAX, DICE, and CINEMA CubeSats.

2.2.2 Federal CubeSats

Recently the US federal government has started to see the utility of CubeSats. In particular, the National Reconnaissance Office (NRO) has been actively buying CubeSat busses and providing

them to various educational institutions, national labs, and FFRDCs. Teams then build a payload, and the NRO provides a launch [17].

Government-funded CubeSats cannot use amateur radio frequencies for many reasons, including the fact that teams are paid to build and operate the spacecraft, and encrypted links are typically used. Due to these requirements, the federal government has been very active in funding radio manufacturers to design and build CubeSat radios. Over time, these designs will become available to the general community, although prices may be too high for all but the well-funded satellites.

QbX: Two of these 3U spacecraft flew on the second flight of the SpaceX Falcon 9 on 8 December 2010. The primary mission was a communications experiment using an experimental spacecraft radio. The spacecrafts communicated with the existing Mobile CubeSat Command & Control (MC3) System, built by the NRL [18]. Various experiments were conducted with the UHF telemetry radios, including passing data from one spacecraft to the other via an MC3 station. Crosslinks between spacecraft were not attempted [19].

AeroCube: The Aerospace Corporation has a long history of flying small satellites. Most of their CubeSats have used a 915 MHz spread-spectrum radio locked on a single frequency. They are using an experimental license with a data rate of 38.4 kbaud. Three similar 1U Aerocube-4 satellites flew on the latest NROL-36 launch on 13 September 2012 with the CINEMA spacecraft mentioned above [20].

3 Higher Frequency Communications

While beginner CubeSats will probably always use UHF amateur radio frequencies due to equipment and license availability, high-performance and military CubeSats are beginning to use higher frequencies for communications. DICE is barely above the UHF amateur radio band, and CINEMA is using 2.2 GHz.

As CubeSats' communications transition to these higher frequencies, the radios and ground stations get difficult and expensive to build. However, much more bandwidth is available in all the satellite services, including the amateur radio service, should teams decide they fit there. Japanese CubeSats scheduled for launch from the International Space Station in October 2012 are using 5.83 GHz and Ku-band transmitters.

4 Conclusion

CubeSat communications systems are maturing at a rapid pace. Five years ago, the only alternative to modified COTS amateur radio equipment was low-performance ISM radios. The fastest communications system had an effective throughput in the tens of kilobytes per second. Today, we see several radio manufacturers providing Megabit-class transmitters compatible with the CubeSat size and power restrictions. As CubeSat transmitters become higher in frequency, more bandwidth is available for high-speed communications.

References

- [1] Jordi Puig-Suari, et al. "CubeSat Developments at Cal Poly: The Standard Deployer and PolySat." In Proceedings of the 45th Annual Meeting of International Society for Optical Engineering (SPIE). Paper 4136-13. July-August 2000.
- [2] Daniel Oltrogge and Kyle Leveque. "An Evaluation of CubeSat Orbital Decay." In Proceedings of the 25th Annual AIAA/USU Conference on Small Satellites. SSC11-VII-2. Logan, Utah. August 2011.
- [3] Derek Huerta. "Development of a Highly Integrated Communication System for use in Low Power Space Applications." Masters Thesis. California Polytechnic State University, San Luis Obispo. May 2006.
- [4] Bryan Klofas, Jason Anderson, and Kyle Leveque. "A Survey of CubeSat Communication Systems." Presented at the 5th Annual CubeSat Developers Workshop. San Luis Obispo, California. April 2008.
- [5] David Klumpar. "CubeSat Lessons Learned: Two Launch Failures Followed by One Mission Success." In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-II-4. Logan, Utah. August 2012.
- [6] Matthew Handley. "The On-Orbit Performance of the HRBE (E1-P) CubeSat Nearing Nine Months in LEO." Presented at the 9th Annual CubeSat Summer Workshop. Logan, Utah. August 2012.
- [7] Hans van de Groenendaal. Personal Communication. 22 September 2012.
- [8] Therese Jorgensen. "CubeSat-based Science Missions for Space Weather and Atmospheric Research: A new NSF Program." Presented at the 5th Annual CubeSat Developers' Workshop. San Luis Obispo, California. April 2008.
- [9] James Cutler, John Springmann, Sara Spangelo, and Hasan Bahcivan. "Initial Flight Assessment of the Radio Aurora Explorer." In Proceedings of the 25th Annual AIAA/USU Conference on Small Satellites. SSC11-VI-6. Logan, Utah. August 2011.
- [10] John Springmann, Benjamin Kempke, James Cutler, and Hasan Bahcivan. "Initial Flight Results of the RAX-2 Satellite." In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-XI-5. Logan, Utah. August 2012.
- [11] Chad Fish, et al. "DICE Mission Design, Development, and Implementation: Success and Challenges." In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-XI-1. Logan, Utah. August 2012.
- [12] Jacob Gunther. "DICE Telemetry Overview and Current Status." Presented at the CHDC Meeting after the 9th Annual CubeSat Developers' Workshop. San Luis Obispo, California. April 2012.
- [13] Bryan Klofas. "Frequency Allocation for Government-funded CubeSats: NSF Paves the Way." In Proceedings of the AMSAT-NA Symposium. San Jose, California. November 2011.
- [14] David Glaser and Karla Vega. "CINEMA: CubeSat for Ions, Neutrals, Electrons, MAgnetic fields." Presented at the 6th Annual CubeSat Developers' Workshop. San Luis Obispo, California. April 2009.
- [15] CINEMA Stage 4 Certification of Spectrum Support. Control Number SPS-18192/1. 6 September 2011.
- [16] Bryan Klofas. "CubeSat Frequency Allocation." Presented at the 9th Annual CubeSat Developers' Conference. San Luis Obispo, California. April 2012.
- [17] Maj David Shultz, et al. "Colony: A New Business Model for Research and Development." In Proceedings of the 24th Annual AIAA/USU Conference on Small Satellites. SSC10-IV-2. Logan, Utah. August 2010.
- [18] Giovanni Minelli. "Mobile CubeSat Command & Control (MC3) Ground Stations." Presented at the 9th Annual CubeSat Summer Workshop. Logan, Utah. August 2012.
- [19] Stephen Arnold, et al. "QbX - The CubeSat Experiment." In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-XI-4. Logan, Utah. August 2012.
- [20] David Hinkley. "AeroCube 3 and AeroCube 4." Presented at the 9th Annual CubeSat Summer Workshop. Logan, Utah. August 2012.



Space@VT Cubesat Efforts

Presented at the 2012 AMSAT Space Symposium

Presenters:

Robert W. McGwier, N4HY

Zachary J. Leffke, KJ4QLP



<http://www.space.vt.edu/>

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Symposium Presenters



Robert W. McGwier, Ph. D.

Callsign: N4HY

Virginia Tech ECE Research Professor

Hume Center for National Security and Technology

Director of Research

Former Vice President of Engineering, AMSAT



Zachary J. Leffke

Callsign: KJ4QLP

Virginia Tech Graduate Student, MSEE

Hume Center for National Security and Technology

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Agenda

- Space@VT Overview
 - Research Interest and Capabilities
 - Research Facilities
 - Project Examples
- Space@VT Cubesat Efforts
 - DUSTIE
 - LAICE
 - FOX-1
- Virginia Tech Cube Satellite Control Facility

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- **Space@VT Overview**
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Space@VT Overview



Our mission is to provide forefront research, instruction, and educational outreach in the fields of space science and engineering utilizing a holistic approach of theoretical modeling, advanced simulation techniques, space system and instrument design, and experimental data acquisition, analysis and interpretation.



Director
Professor Wayne Scales, Ph. D.



Assistant Director
Professor Robert Clauer, Ph. D.



images from: <http://www.space.vt.edu/>

- Collaboration between VT ECE and AOE
- 12 Virginia Tech Faculty Members (Including Dr. McGwier)
- 3 Research Associates
- Over 25 Graduate Students

5

Space@VT Overview

Research Interest and Capabilities

Research Interests:

- Upper Atmospheric and Space Plasma Physics
- Space Weather Investigations
- Spacecraft Dynamics and Control
- Spacecraft Advanced Propulsion Techniques
- Spacecraft Environmental Interactions

Research Capabilities:

- Satellite Mission Design and Remote Sensing
- Space-based Instrument Development
- Ground-based Instrument Development
- Spacecraft Modeling, Simulation, and Design
- Physics-based Modeling, Simulation, and High Performance Computing
- Global Navigation Satellite System Receiver Design

Reference: <http://www.space.vt.edu/>

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Space@VT Overview

Research Interest and Capabilities

Research Facilities:

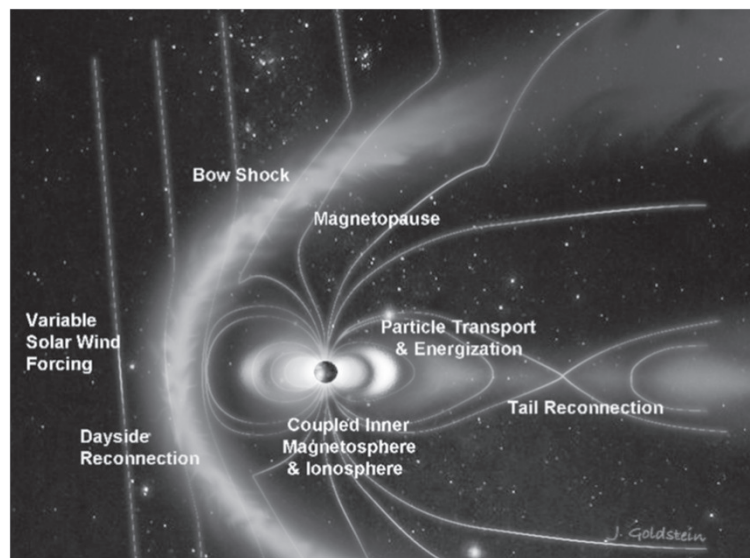
- Global Navigation Satellite System GNSS Laboratory
- Space Systems Simulation Laboratory
- Aeronomy/Remote Sensing Laboratory
- Advanced Space Computation Laboratory
- **SuperDARN Space Weather Radar Facility**
- Space Plasma Chamber
- **Magnetosphere - Ionosphere Science Team (MIST)**

Reference: <http://www.space.vt.edu/>

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Space@VT Overview

SuperDARN - Super Dual Auroral Radar Network



Reference: <http://vt.superdarn.org/tiki-index.php>

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Space@VT Overview

SuperDARN - Super Dual Auroral Radar Network



- Over 25 Radar Locations around the world
- Operating Frequency: 8 – 20 MHz
- Field Of View: Polar Regions of Earth
- Observes the motion of charged particles (plasma) in the ionosphere and other effects.
- Provides insight into space weather hazards including high altitude radiation exposure and disruptions to communications networks, navigation systems (GPS), and the electrical power grid.
- Currently: 6 VT Faculty and Staff, 7 VT Graduate Students
- 13 Authored Publications, 19 Co-Authored Publications

Northern Radar Institutions:

- Virginia Tech: 6 Radar Locations
- Dartmouth College
- University of Leicester
- Nagoya University
- University of Saskatchewan
- National Institute of Information and Communications Technology
- University of Alaska, Fairbanks
- CNRS/LPCE
- JHU Applied Physics Laboratory

Southern Radar Institutions:

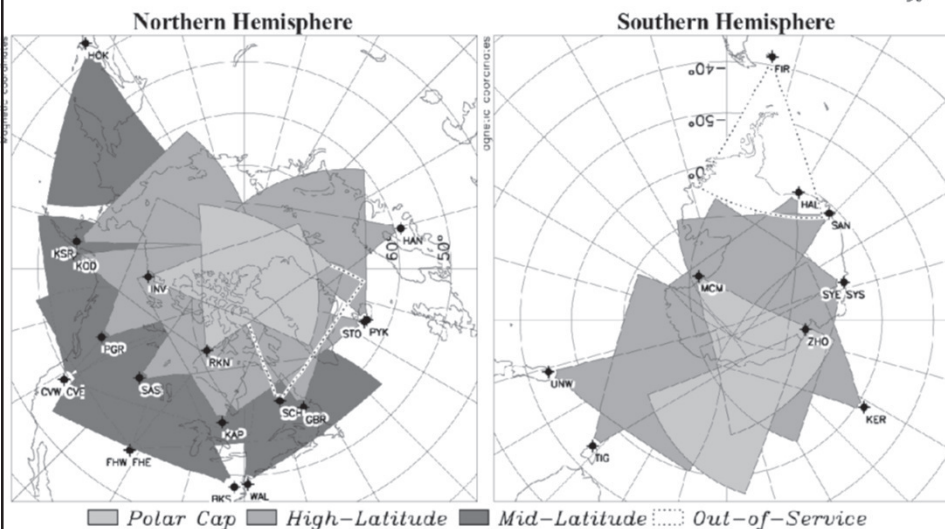
- British Antarctic Survey
- CNRS/LPCE
- University of Alaska, Fairbanks
- South African National Space Agency
- National Institute of Polar Research
- La Trobe University
- Polar Research Institute of China

Reference: <http://vt.superdarn.org/tiki-index.php>

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Space@VT Overview

SuperDARN - Super Dual Auroral Radar Network

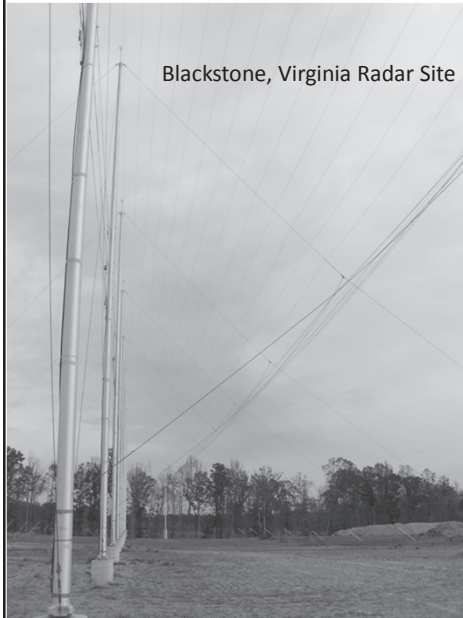


Reference: <http://vt.superdarn.org/tiki-index.php>

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Space@VT Overview

SuperDARN - Super Dual Auroral Radar Network



Blackstone, Virginia Radar Site



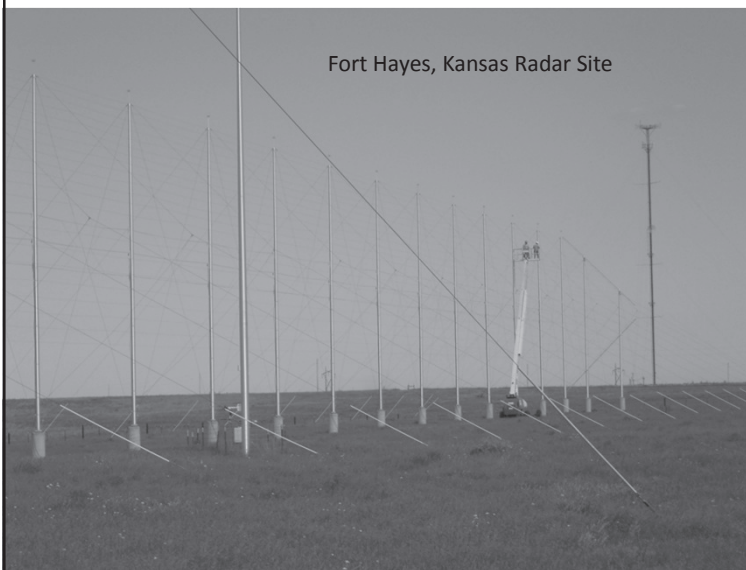
Kapuskasing, Canada Radar Site

Reference: <http://vt.superdarn.org/tiki-index.php>

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Space@VT Overview

SuperDARN - Super Dual Auroral Radar Network



Fort Hayes, Kansas Radar Site

Reference: <http://vt.superdarn.org/tiki-index.php>

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Space@VT Overview

SuperDARN - Super Dual Auroral Radar Network



Fort Hayes, Kansas Radar Site

Reference: <http://vt.superdarn.org/tiki-index.php>

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Space@VT Overview

Magnetosphere - Ionosphere Science Team (MIST)

We primarily investigate the interaction between the Earth's "magnetosphere" and its ionosphere. The magnetosphere is the cavity formed by the interaction between the solar wind and Earth's main magnetic field, that is generated by electric currents deep within the planet's core. The ionosphere is the top-most layer of the atmosphere, extending into space, where the atoms have been ionized by the ultraviolet rays from the Sun, forming a conductive "plasma". The magnetosphere is also filled with plasma. The regions of the magnetosphere that have magnetic field line "footprints" in either of two, oval-shaped regions in the ionosphere surrounding the polar caps collectively account for the aurora. Large-scale current systems and other effects carry momentum and energy from high to lower altitudes, resulting in electric fields and currents in the ionosphere. The driving force of this energy flow is the solar wind and the "Interplanetary Magnetic Field," known as the "IMF," which is carried outward from the Sun by the solar wind. The electric currents in the ionosphere produce variations in the magnetic field at the surface of the Earth. Measurements of these variations with magnetometers are often used to study the Magnetosphere-Ionosphere system.

Principal Investigator: C. Robert Clauer (Bob), Ph. D., Co-Director of Space@VT

Reference: <http://mist.nianet.org/>

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Space@VT Overview

Magnetosphere - Ionosphere Science Team (MIST)

AAL-PIP deployment team members around the AAL-PIP system located at the South Pole (January 4, 2012)



Reference: <http://mist.nianet.org/>

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 - DUSTIE
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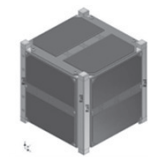
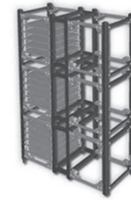
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Space@VT Overview

Cubesat Efforts

The Satellites

- DUST Sounder and Temperature Imager Experiment (DUSTIE)
Size: 3U
- Lower Atmosphere/Ionosphere Coupling Experiment (LAICE)
Size: 6U (2U x 3U or "Sixpack")
- AMSAT FOX-1
Size: 1U



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Cubesats and Space@VT

DUST Sounder and Temperature Imager Experiment (DUSTIE)

VT Faculty: Dr. Scott Bailey & Dr. Robert McGwier

MISSION:

Determine the global distribution of cosmic smoke in the atmosphere. DUSTIE will use a digital camera to image the Sun at $0.420 \mu\text{m}$ during spacecraft sunrise and sunset. This will provide measurements to characterize the smoke distribution over the altitude range of ~40 to 90 km.

(information from: <http://adsabs.harvard.edu/abs/2009AGUFM5M33C1575M>)



Images from: <http://www.cubesatkit.com/content/news-2010.html>

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Cubesats and Space@VT

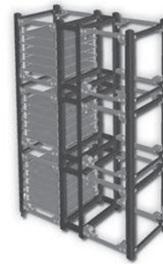
Lower Atmosphere/Ionosphere Coupling Experiment (LAICE)

VT Faculty: Dr. Greg Earle

MISSION:

"We're basically trying to measure the wind in a vacuum." Neutral particles move when the atmosphere changes temperature, like wind on the earth's surface. Dr. Earle is developing a new kind of transducer to measure these neutral winds. The instrument is basically a parallel plate capacitor in which one plate is a flexible silicon membrane with a thin metal coating, change the distance between the plates, the capacitance changes.

(information from: Space@VT brochure, available at <http://www.space.vt.edu/>)



(images from: http://www.clyde-space.com/cubesat_shop)

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Cubesats and Space@VT

FOX-1

Project Leader: Anthony Monteiro
VT Faculty: Dr. Robert McGwier

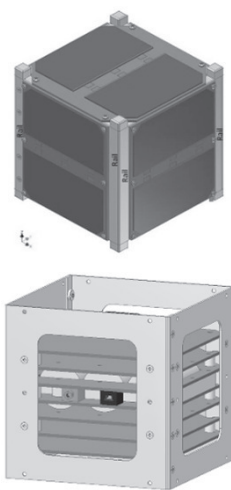
MISSION:

Fox-1's Primary mission will be to carry an FM repeater operating in the amateur radio 70cm (uplink) and 2m (downlink) frequencies. This will provide a service similar to the now dead AO-51 communications services. In addition to this the cubesat will support a Penn State University 3-axis MEMS gyro sensor developed as a senior design project.

VT's Part of the Mission: Imaging Experiment (Not SSTV)



AMSAT Fox



(images from Power Point Presentations available at <http://www.amsat.org/amsat-new/fox/>)

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- Space@VT Overview
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- **Virginia Tech Cube Satellite Control Facility**

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Virginia Tech Cube Satellite Control Facility

Primary Mission:

To provide Cube Satellite Tracking Telemetry and Control (TT&C) services as well as science payload data services for Virginia Tech cube satellites as well providing support and capabilities to ongoing US government sponsored research programs here at Virginia Tech.

Secondary Mission:

To provide the same cube satellite services to other entities involved in cube satellite missions through cooperation via the Global Educational Network for Satellite Operations (GENSO) Network.

The Problem:

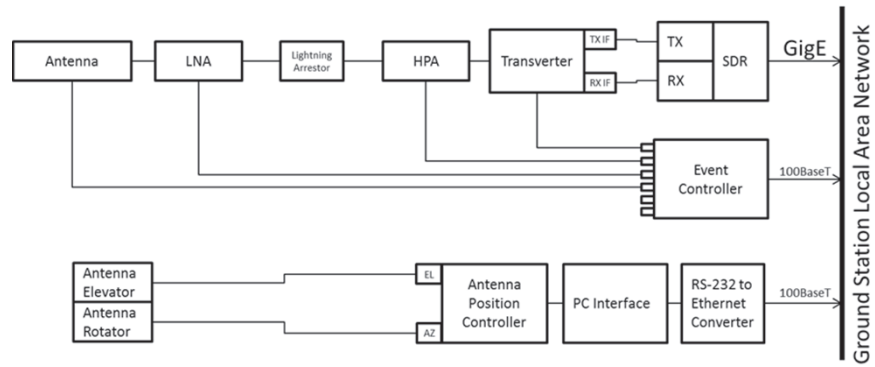
Diverse protocols and modulation schemes are used in currently existing cube satellites communications.

Virginia Tech Solution:

To utilize Software Defined Radio technology in conjunction with quality hardware in the ground control facility to accomplish the mission.

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Virginia Tech Cube Satellite Control Facility
RF Chain and Control Chain



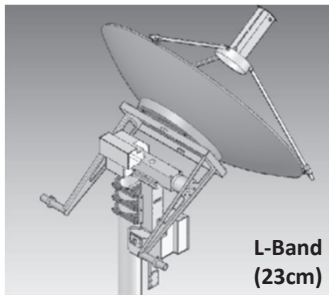
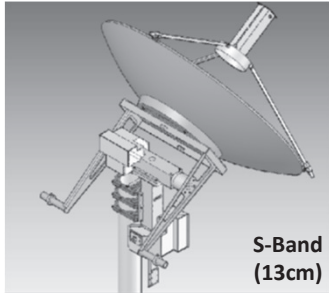
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Virginia Tech Cube Satellite Control Facility
Frequency Selection

Amateur Radio Band	Frequency Range	Satellite Sub Band	Note
2 meters (VHF)	144 to 148 MHz	144 to 146 MHz	
70 centimeters (UHF)	430 to 450 MHz	435 to 438 MHz	
23 centimeters (L-Band)	1240 to 1300 MHz	1260 to 1270 MHz	Uplink Only
13 centimeters (S-Band)	2300 to 2310 MHz and 2390 to 2450 MHz	2400 to 2403 MHz	

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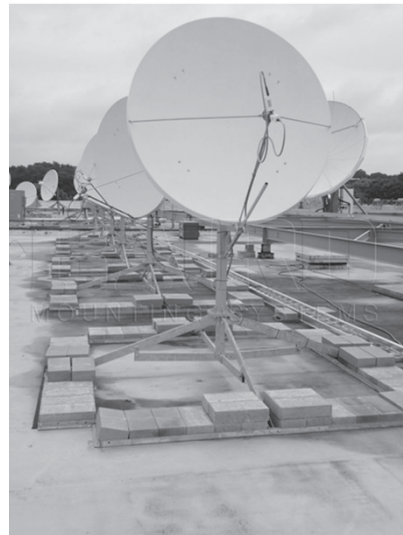
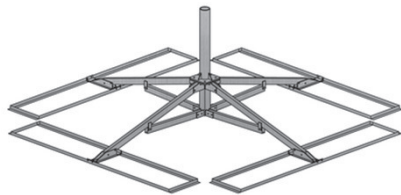
Virginia Tech Cube Satellite Control Facility
The Antennas



- M² Antennas Inc.
- Circular Polarization
- RHCP/LHCP Sense Selectable
- High Gain, Directional

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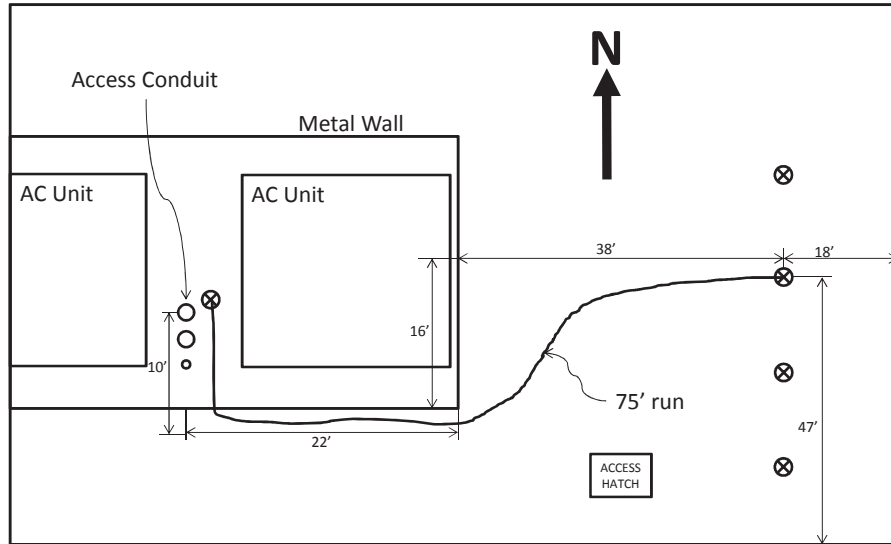
Virginia Tech Cube Satellite Control Facility
The Antennas



NOTE: This is the exact model we would receive from M2 Antennas Inc. with the AZEL1000 System

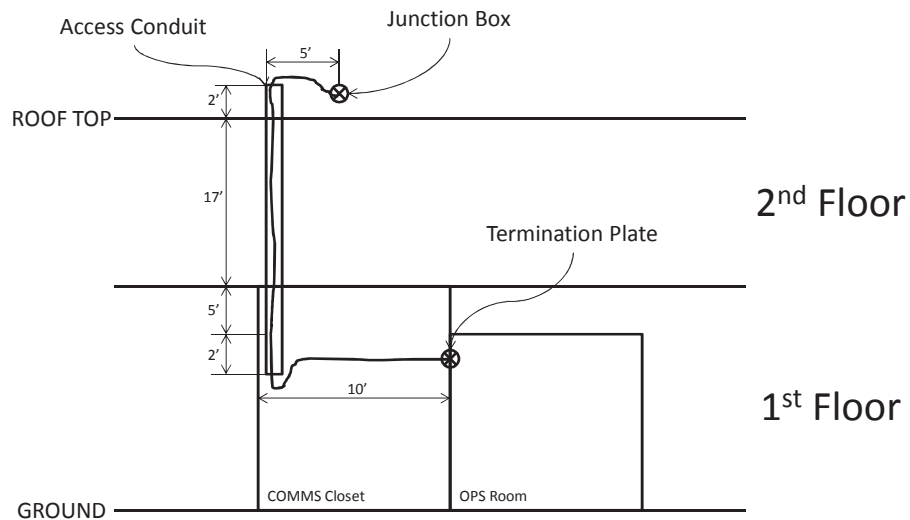
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Virginia Tech Cube Satellite Control Facility
Cable Runs



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Virginia Tech Cube Satellite Control Facility
Cable Runs

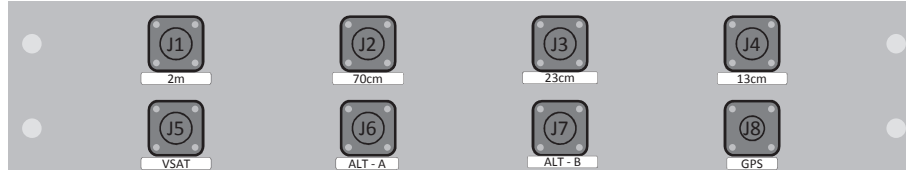


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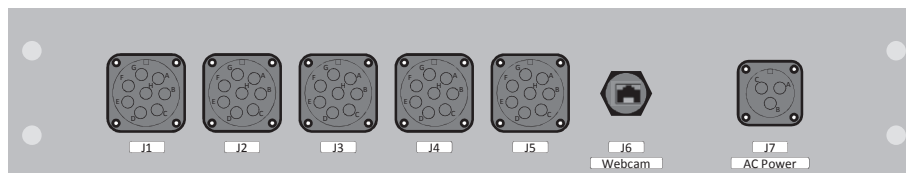
Virginia Tech Cube Satellite Control Facility

Control Room Termination Plates

RF Cable Termination Plate



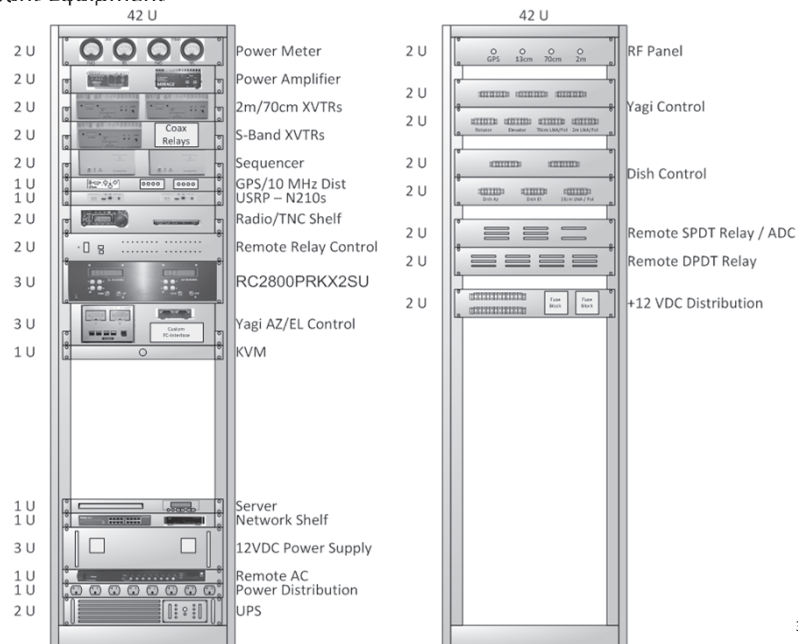
Control Cable Termination Plate



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Virginia Tech Cube Satellite Control Facility

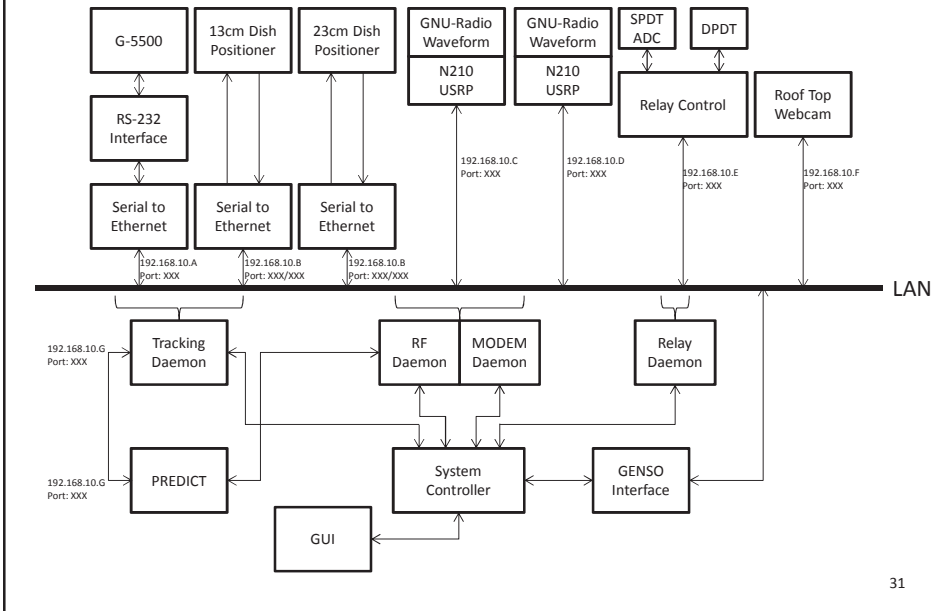
Rackmount Equipment



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Virginia Tech Cube Satellite Control Facility

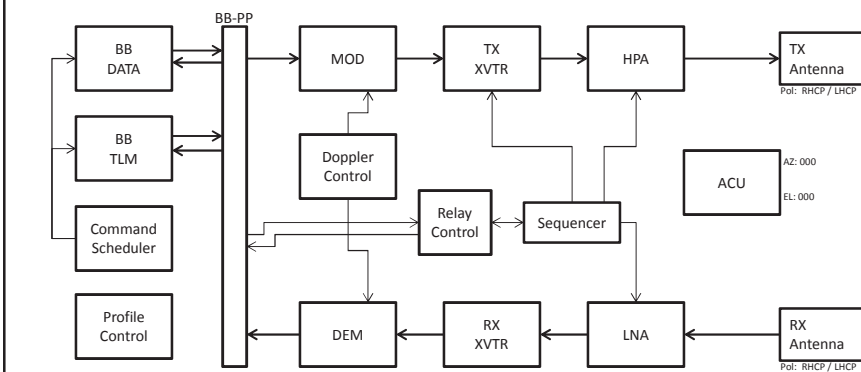
Network and Control Daemons



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Virginia Tech Cube Satellite Control Facility

Graphical User Interface



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Mars-lander ARISS Robotics Exploration Activity (MAREA)

Mark Spencer, WA8SME, ARRL Education & Technology Program Director

Abstract. This short paper and accompanying power point presentation describes a concept that uses standard packet transmission protocols to send movement commands to remote robotic platforms for execution. The concept tentatively called MAREA has potential to be used by schools in support of their STEM curriculum.

I have observed an increased interest in using ham radio packet radio transmissions as data links to connect remote ground stations to deployed remote sensor package systems (i.e., buoys, high altitude balloons, etc.). The use of packet radio for data links, if done correctly, can be an effective and unobtrusive use of the mode. The data being transmitted is simply embedded in the text portion of the packet transmission, APRS position reporting and the use of the APRS system for packet relay, and entry into Internet gateways for wide dissemination is an added benefit for the use of the mode as a data link.

While supporting the AMSAT/ARRL effort to justify the upload of a replacement ARISS radio on the ISS, an idea surfaced to use packet transmissions to control school developed robot platforms to simulate real-world robotic control as is currently being done with the series of Mars rovers as a possible added use of the ARISS radio. There historically has been a unit presented during the ARRL Teachers Institutes (TI) that showed teachers how to do a “Mars Lander” like simulation using the Parallax BOE-BOT platform that is resource provided to the teachers during the TI. The Mars Lander simulation is the culminating activity to tie the five pillars of the TI curriculum together in one final grand show (the five pillars: basic electronics, the science of radio, bringing space into the classroom, microcontroller programming, and basic robotics). Based on that previous experience, and the experience we have had with the ARRL TI2 Space program which focuses on using satellites in the classroom, it quickly became apparent that the suggested use of ISS digipeated packets to control a Mars Lander simulator would be a natural extension of the TI program and would add to the portfolio of education related activities available through the ARISS radio as well as other AMSAT ham satellite platforms.

In a matter of days, two robots were constructed and programmed to respond to simple commands sent via packet radio. The final proof of concept quickly followed when Matt Severin, N8MS was controlling a robot in Connecticut from his home in Michigan via commands sent through the ISS APRS system. MAREA, within about a week’s time, was a reality. The accompanying power point slides gives an overview of the MAREA concept which is very much in its infancy but is gaining traction very quickly as it is presented to the ham radio and education audiences alike.

The potential of the MAREA concept is limitless. Plans are already in the works to include a simple unmanned underwater vehicle (the Sea Perch platform) in the portfolio of vehicles controlled through the MAREA concept. By the time you read this, the development of the Sea Perch motor controllers and sensor package will be well on its way to breaking the hard wired tether to

the shore operator and connecting a remote operator to the UUV via command sent via the ISS and packet radio.

As an aside, the most difficult part of developing this concept was to come up with a name for it. There have been a number of iterations before it was reluctantly decided to temporarily call it MAREA. I suspect that this moniker will not last very long so expect a name change in the future.

If you have questions about MAREA, please contact Mark Spencer, WA8SME, at m Spencer@arrl.org, or 860-381-5335.

AMSAT Fox-1 and the NASA ELaNa Program

by Tony Monteiro AA2TX

aa2tx@amsat.org

Introduction

The CubeSat concept was originally developed by professors Jordi Puig-Suari at Cal-Poly and (AMSAT member) Bob Twiggs at Stanford as a way to reduce satellite launch costs making space more accessible to university student projects. This effort has been highly successful. Today, a US-based CubeSat launch can be had for around \$120k. Nonetheless, this is still a substantial sum for a university or AMSAT to raise for a launch.

To help stimulate interest in CubeSats as part of their Science, Technology Engineering and Math (STEM) education goals, NASA developed the "Educational Launch of NanoSat" (ELaNa) program. This program provides a free CubeSat launch as an auxiliary payload on a NASA mission. The first ELaNa request for proposal (RFP) was issued in February of 2010. Since this was aimed at promoting STEM education, only accredited educational institutions were eligible to apply. Three CubeSats were selected and launched in March of 2011 on the NASA Glory mission. Unfortunately, the launch vehicle failed and all of the satellites were lost. Nonetheless, NASA was pleased by the interest that was generated and has expanded the program. When their 2011 CubeSat Launch Initiative was announced, it included new opportunities for US-based, non-profit organizations making AMSAT eligible to participate.

AMSAT is of course always looking for a free launch, so an effort was initiated to make the required adjustments to our *Fox-1* program to make it consistent with NASA requirements and to develop our proposal. The key issue in order to qualify is to explain how the project helps NASA meet their education and science goals. These are identified and described in the *NASA Strategic Plan*¹ and the *NASA Education Strategic Coordination Framework*².

AMSAT's complete *Fox-1* proposal to NASA included very detailed technical and project information and was a total of 159 pages long. That would be far too much to include here but key highlights including portions of the abstract and main body of the proposal are presented in the following sections.

Fox-1 ELaNa Proposal Abstract

AMSAT is a non-profit, research and education organization. Since its founding in 1969, it has been a pioneer in the development and applications of small and micro satellites. AMSAT projects are funded through donations and passionate volunteers do all of the technical work. While most of our volunteers are highly experienced industry veterans or retirees, AMSAT welcomes contributors of all ages and technical abilities and provides training as needed. With over 3,000 members, AMSAT is well represented throughout the ranks of industry, NASA and the university satellite community. Many AMSAT members have been technical advisors on university CubeSat projects.

AMSAT *Fox-1* is a 1-Unit CubeSat and the primary focus of the project is education. The satellite will host a two-way FM communications transponder and an experiment payload. The communications package is specifically designed to be *easy-to-use* requiring only a simple *walkie-talkie* style radio combined with a small hand-held antenna. Using amateur radio frequencies, it will be open and available to the general public. This simple, low-cost on-orbit capability facilitates a wide spectrum of STEM educational opportunities from inspiring young minds and engaging secondary school students to educating teachers and university students.

In the classroom, having an accessible on-orbit asset will allow schools, teachers and students to participate in space technology with a *hands-on* experiential learning approach. This approach can help make difficult STEM concepts far more interesting and easier to grasp. AMSAT aims to make STEM education *fun*.

To inspire, engage and educate the next generation...



The proposal front cover photo showed 5th grade students participating in a hands-on STEM learning experience offered through their school's gifted and talented program. These elementary school students learned about space communications first hand, as they accessed the AMSAT AO-51 satellite. Though AO-51 has failed due to battery problems, Fox-1 will ensure continued availability of these learning opportunities.

On the informal side, *Fox-1* will provide a technology *stepping stone* that is easily accessible to the average citizen, requiring only an amateur radio license to participate. This can generate interest in STEM topics through a hobby activity and may even lead to

active participation in satellite technical advancement. *Fox-1* will also enable informal groups with educational goals, such as youth scouting organizations, to help inspire their members to embrace STEM through participatory activities using the satellite. This promotes technology and space literacy among the general public.

In addition to the communications package, *Fox-1* will host an experiment payload developed by university students. AMSAT is sponsoring this development as a *capstone* project at Penn State University for the 2011-2012 academic year. Senior engineering students are developing an attitude determination experiment for graduation credit with mentoring and guidance provided by AMSAT. In addition to the hands-on, real-world experience provided to the students, the experiment data will be valuable in planning future satellite projects. All of the experiment and satellite telemetry data will be collected and stored on our Internet server. This data will be made publicly available for use in the classroom by educators and shared with the general CubeSat community.

The Fox-1 project has an educational focus and we conducted a non-competitive merit review. Our review panel members included academic and industry experts who were not on the Fox-1 development team. The merit review panel concluded that the project "meets NASA needs and goes beyond." The merit review team also offered suggestions for improving our education message and these have been incorporated in the *Fox-1* project.

We conducted a non-competitive feasibility review. Our review panel members included academic and industry experts who were not on the Fox-1 development team. The feasibility review committee concluded that there was "a very high probability of success" and noted that the AMSAT team "well exceeded typical other CubeSat teams in depth and breadth of skill and experience." The feasibility review team offered suggestions for improving our development process and these have been incorporated in the *Fox-1* project.

Compliance Checklist	Section
☒ Respondent is a NASA center, a U.S. not-for-profit organization, or an accredited U.S. educational organization	1
☒ Proposal includes demonstration of the benefits to NASA	9
☒ Proposal identifies a project focus area	1
☒ Proposal includes a description of the merit review process and outcome	10
☒ Proposal includes a description of the feasibility review process and outcome	11
☒ Proposal must fully comply with the P-POD integration requirements	2
☒ Proposal includes a completed Mission Parameters Table.	8
☒ Proposal includes a schedule for remaining CubeSat development that supports a launch in 2012, 2013, or 2014	6
☒ Proposal includes funding commitment letters demonstrating sufficient financial support for remaining CubeSat development	Appendix 2

Fox-1 ELaNa Proposal Body

1 Introduction

1.1 Eligibility

AMSAT, The Radio Amateur Satellite Corporation, was incorporated in 1969 in Washington D.C. It is a non-profit 501(c)(3) research and education organization listed in IRS Publication 78. AMSAT has over 3,000 members.

1.2 Mission Overview

AMSAT volunteers and undergraduate university students are developing the *Fox-1* CubeSat. The primary focus of this project is to support STEM education. *Fox-1* will host a two-way FM communications transponder and an experiment payload. The communications package will be specifically designed to be easy-to-use requiring only a simple *walkie-talkie* style radio combined with a small hand-held antenna. Using amateur radio frequencies, it will be open for use by the general public. This capability will facilitate a wide spectrum of STEM educational opportunities from inspiring young minds and engaging K-12 pupils to educating teachers and university students. Collaboration with ARRL, The National Association for Amateur Radio will result in educator training seminars that will include using *Fox-1* in classroom activities.

In addition to the communications package, *Fox-1* will host an experiment payload. AMSAT is sponsoring a *capstone* project at Penn State University for the 2011-2012 academic year. Senior engineering students will be participating for graduation credit with mentoring and guidance provided by AMSAT volunteers. The project will involve designing and constructing an attitude experiment based on a 3-axis, micro-electro-mechanical gyroscope. The experiment data will measure the performance of the satellite's magnetic stabilization system. While the primary focus of the experiment payload is to provide a hands-on, real-world educational experience for the students, the experiment data will be valuable in planning future CubeSat projects.

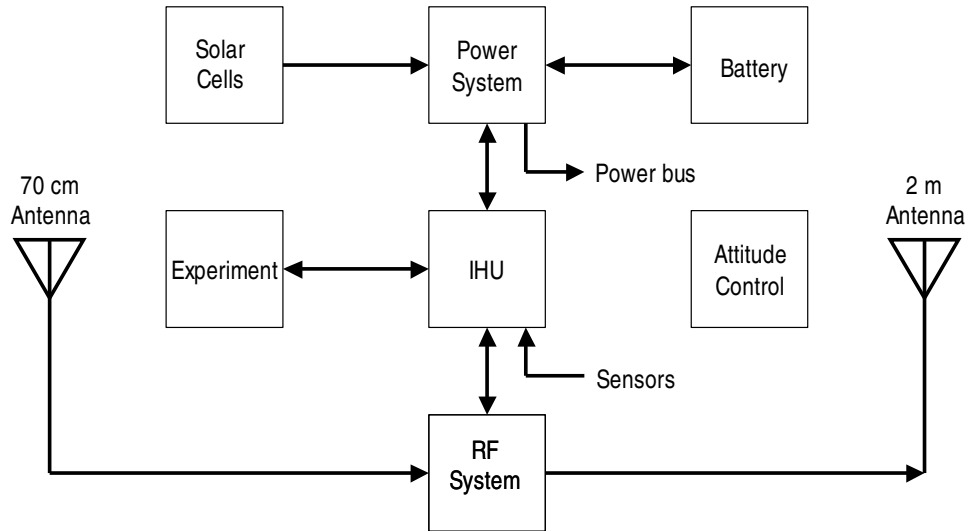
1.3 CubeSat Project Details Table

CubeSat Project Details						
Focus Area	Student Involvement	NASA Funding		Sponsor	Proposal Collaboration	
		Yes or No	Organization		Yes or No	International-Yes or No
Education	Yes	No		AMSAT	Yes	No

AMSAT is collaborating with ARRL, The National Association for Amateur Radio. ARRL will be incorporating *Fox-1* into their professional development seminars for educators. A letter of support from ARRL and a copy of the Teacher Institute program brochure are included in APPENDIX 2.

2 *Fox-1* Spacecraft Description

Fox-1 is a 1U CubeSat. It will be designed and tested to be fully compliant with the Launch Services requirements as described in “Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (P-POD) and CubeSat Requirements Document (LSP-Req-317.01).”



The major subsystems of the *Fox-1* satellite include the attitude control system, the power system, an internal housekeeping unit (IHU,) the radio (RF) system and the experiment payload as shown in the figure above. There are six solar panels with one on each face of the CubeSat. The power system uses the power generated by the solar panels to drive the power bus and charge the battery. In eclipse, the power needed to run the satellite comes from the stored energy in the battery. The internal housekeeping unit (IHU) is the brains of the satellite and is based on an ultra-low-power microcontroller. The RF system includes a FM receiver, a FM transmitter and the necessary logic to operate either under control of the IHU or as an automatic FM repeater. The satellite uses passive magnetic stabilization and a photon motor to spin the satellite for thermal considerations. The antennas are monopoles aligned with the satellite's magnetic axis to minimize spin-modulation. The experiment payload, being developed by students at Penn State, will include a 3-axis micro-electro-mechanical gyroscope and a microcontroller to calculate the satellite spin rate, direction and off-axis "wobble." This will measure the performance of the attitude stabilization system. Project technical documents are included in APPENDIX 3.

3 Project Organization and People

AMSAT engineering is staffed completely by passionate volunteers and is organized as project teams. Each project has a project leader who is responsible for the overall success of the project including the planning, execution, monitoring, control, completion and budget.

The project work and activities are structured by function or subsystem. A self-directed individual or team is responsible for each of these functional parts of the project. There is no official hierarchy or management within a functional team. AMSAT relies on outstanding informal leaders who have demonstrated superior technical and influence skills to provide guidance to their functional team as well as the entire project. This structure has been used on previous satellite projects and works very well for our distributed volunteer teams.

AMSAT has a university program manager who is responsible for representing AMSAT on the experiment team. The experiment team is staffed with six undergraduate students and a faculty member from Penn State. There is also an AMSAT technical mentor on the team to provide technical assistance.

In addition to the Penn State students, two undergraduate students are working on Fox-1 as AMSAT volunteers. AMSAT recognizes that school is their top priority and welcomes their participation.

The current list of AMSAT and Penn State team members is provided in the Project Plan in APPENDIX 3. Resumes for key AMSAT team members are provided in APPENDIX 1.

4 Engineering Process

Fox-1 follows the AMSAT engineering process. This documented process describes a project *lifecycle* model and includes Concept, Design, Implementation & Test, and Operations & Maintenance phases. Both formal and informal reviews are used within the phases to maintain system consistency, detect errors as early as possible and to facilitate a clear understanding of the project status. A copy of the AMSAT engineering process is included in APPENDIX 3.

5 Risks and Mitigation

The following areas have been identified as the major project risks and the means of mitigation.

5.1 Volunteer Staff - High Risk

AMSAT's engineering team is all volunteers. Unforeseen family and day-job related events can and have caused loss of volunteer time availability. AMSAT has no capacity to hire replacements. This is the major schedule risk. To mitigate this risk, AMSAT:

- Makes an upfront attempt to staff each functional area with more than one volunteer
- Constantly recruits new volunteers
- Looks to our "bench" of past volunteers for short term assignments if needed
- Includes 3 months of contingency time in the development schedule

5.2 Space Radiation - Medium Risk

The *Fox-1* satellite has a target mission lifetime of 5 years in orbit. The target orbit is sun-synchronous at 650 km altitude, which will cause substantially higher radiation

exposure than an ISS orbit. AMSAT cannot afford to use Rad-Hard components and COTS components are generally sensitive to radiation. To mitigate this major technical risk, AMSAT will:

- Include a team member who assigned to research radiation
- Model the radiation exposure
- Test key components for radiation sensitivity
- Design the electronics systems for fault tolerance
- Use additional radiation shielding to protect key components.

5.3 New, High Performance Components - Low Risk

Several new high-performance components are recently available that have considerable benefits for use in the *Fox-1* satellite. Since they are new, team members have no experience using these components and are unfamiliar with their limitations, especially undocumented or unspecified behaviors. These include components such as a high-efficiency RF power amplifier, an ultra low power microcontroller and a solar panel maximum power point tracker. Since these risks can be reasonably controlled, they pose a low risk level after mitigation but remain as the second source of technical risk. To mitigate these risks, AMSAT plans to:

- Prototype specific circuits and test them in laboratory settings
- Test using manufacturers evaluation cards where possible
- Prove-in new components before design-in to the satellite

5.4 Penn State Student Developers - Low Risk

The experiment card for the *Fox-1* satellite is being designed by undergraduate engineering students. These students have limited technical experience. They are also expected to graduate in May 2012 and cannot be counted on after that to work on the project. Since the key NASA benefit from student involvement is training, that benefit is not at risk if the students don't finish the experiment card by graduation. In addition, the primary mission of the satellite will operate without the experiment card. However, AMSAT would not be able to obtain our desired experiment data. To mitigate this low technical risk, AMSAT has :

- An AMSAT program advisor to track progress of the student team
- Provided a technical mentor to the students
- A contingency to have AMSAT volunteers complete the experiment

6 Project Status and Timeline

The initial technical and operational investigations of the AMSAT *Fox* satellite program were kicked off in October 2010. A Concept Review was held in April 2011 to review the results of these investigations. After further investigations, the program strategy was refined and endorsed by the AMSAT board of directors in July 2011. *Fox-1* represents the first project planned within a new series of AMSAT CubeSats. The project progress so far includes:

- *Fox-1* project defined - July 2011
- Concept of Operations (ConOps) - Sept 2011
- System Requirements Spec (SRS) - Oct 2011

- Experiment Payload Specification - Nov 2011
- Project Plan draft - completion expected Dec 2011

A second Concept Review was held in October 2011 to review the proposed Fox-1 satellite bus architecture and design. As of November 2011, two subsystems had been prototyped and tested to address technical risk areas. These include the RF power amplifier and the IHU microcontroller.

Key milestone dates for the remaining development work are as follows:

- Preliminary Design Review (PDR) - March 2012
- First complete engineering prototype - July 2012
- Critical Design Review (CDR) - August 2012
- Flight model ready for test - November 2012
- Launch Readiness Review - January 2013
- Launch Target - 2nd half of 2013

Note that the launch target date includes a 3-month contingency interval to mitigate schedule risk.

7 Project Funding

7.1 Indirect Costs

AMSAT engineering resources are expected to be needed for the project. These do not represent direct project costs but are already included in the overall AMSAT engineering budget.

7.2 Direct Costs

Total component and non-recurring engineering (NRE) costs are estimated at \$38,500. Other direct expenses for the project such as travel, meetings, shipping and supplies are estimated at \$25,000. The total of the direct project costs is estimated at \$63,500. In 2011, approximately \$1,500 will be spent on the project leaving \$62,000 needed for 2012.

AMSAT has committed to funding the complete cost of the project including the flight satellite and a complete flight spare unit. In addition, the AMSAT budget includes a launch contingency reserve in the event of a requirement to reimburse NASA. Please see the AMSAT funding commitment letter in APPENDIX 2.

8 CubeSat Mission Parameters Table

CubeSat Mission Parameters								
Mission Name	Mass (kg)	Cube Size	Desired Orbit		Acceptable Orbit Range (minimum)	325 km @ 51.6 degree incl. Acceptable-Yes or No	Readiness Date	Desired Mission Life
Fox-1	1.33	1U	Altitude	650 km	600 km apogee	No	April 2013	10 years
			Inclination	98.2°	40°			

While AMSAT has indicated a 650 km, sun synchronous orbit as our target, the satellite design will accommodate a wide range of orbit altitudes and inclinations. The major consideration is the desire for at least 10 years in orbit.

9 Benefits to NASA

The AMSAT *Fox-1* project addresses a broad spectrum of involvement identified in the NASA Education Strategic Coordination Framework. This includes inspiring youth and the general public via outreach activities to formal education of university students and professional educators.

9.1 Education Goal: Engaging Americans in NASA's mission

"NASA will engage students, educators, families, the general public, and all Agency stakeholders to increase Americans' science and technology literacy."



Photo courtesy of Make Magazine.

Fox-1 will be a publicly available on-orbit asset designed to be *easy-to-use*, requiring only an amateur radio license to participate. This technology *stepping-stone* will help generate interest in STEM topics through hobby activities and will lead to active participation in technical advancement.

Fox-1 will enable groups, such as youth scouting organizations and amateur radio clubs, to promote informal STEM education through activities using the satellite. It offers opportunities for self-learning and improved technology literacy to interested Americans.

Shown in the photo is Diana Eng, a well-known fashion designer, demonstrating a collapsible fabric antenna that she created to communicate through the AMSAT AO-51 satellite. Her article about this project appeared in Make Magazine, which targets a wide audience and promotes technology literacy. Though AO-51 is now experiencing battery problems, *Fox-1* will ensure continued availability of these opportunities for public engagement.

9.2 Education Goal: Attracting and retaining students in STEM disciplines

"NASA will focus on engaging and retaining students in STEM education programs to encourage their pursuit of educational disciplines critical to NASA's future engineering, scientific, and technical missions."



In the classroom, *Fox-1* will allow schools, teachers and students to actively participate in space technology with a unique *hands-on* experiential learning approach that includes communicating through a satellite in orbit. And, while AMSAT encourages everyone to obtain an amateur radio license, the students do not have to have one to be involved. All that is needed is for a licensed teacher or classroom volunteer to be present.

The smiles on these 7th grade students in the photo on the left belie the fact that they are actively engaged in a STEM activity at their school and learning about satellites. The recent AMSAT ARISSat-1 satellite enabled this activity and shows how the *hands-on* approach can help make difficult STEM concepts far more interesting and actually *fun*! ARISSat-1 will de-orbit next year but all of the satellite telemetry data is being collected and stored on an AMSAT Internet server and is openly available for use in the classroom. The *Fox-1* project will assure that this capability will be continued and will include free telemetry decoding and display software.

A letter of support from the Clay Center for Science and Technology at the Dexter School and Southfield School endorsing AMSAT satellites for their educational value is included in Appendix-2.

9.3 NASA Education Outcome 2 - Professional Development

"Attract and retain students in STEM disciplines through a progression of educational opportunities for students, teachers, and faculty."

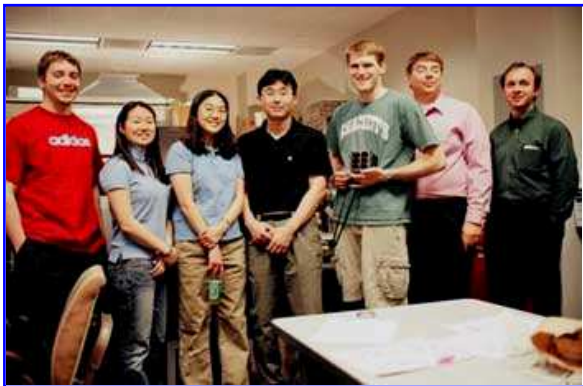


AMSAT is collaborating with ARRL, The National Association for Amateur Radio, to insure that timely and accurate information about *Fox-1* is included in their professional development courses for educators. Each summer, ARRL offers multiple sessions of the Teachers Institute on Wireless Technology, a 4-day expenses paid professional development seminar. The Teachers Institute has provided educators from elementary school to the university level with tools and strategies to introduce basic electronics, radio science,

space technology and satellite communications in their classrooms. The TI-2 seminar, *Space in the Classroom*, focuses on space and satellite communications. Graduate credits are available through these seminars that can be used to satisfy professional growth requirements needed to maintain teaching credentials. A current program brochure and a letter of support for the *Fox-1* project from ARRL are included in APPENDIX 2.

9.4 Education Goal: Strengthening NASA and the Nation's future workforce

"NASA will continue contributing to the development of the Nation's science, technology, engineering, and mathematics workforce of the future through a diverse portfolio of education initiatives that target America's students at all levels"



Over the past several years, AMSAT volunteers have participated in student projects as mentors and advisors at Cornell, SUNY, Auburn, the University of Arizona and the College of New Jersey. These projects have provided undergraduate and post-graduate engineering students with exposure to spacecraft systems design and development.

Building on these successes, AMSAT is sponsoring a *capstone* project at Penn State University for the 2011-2012 academic year. AMSAT is providing funding, mentoring and technical guidance for the students. Senior engineering students will be developing the experiment payload for *Fox-1* for graduation credits. The thrill of knowing that *your* senior project will be going into orbit is a powerful and exciting motivator for the students.

10 Merit Review

The AMSAT *Fox-1* team held a merit review. The review was conducted as an on-line, multimedia teleconference with key members of the *Fox-1* team and a review panel of academic and industry experts.

- What was the merit review process?

The AMSAT team presented a set of power point slides that included an overview of the *Fox-1* mission. Since the focus of *Fox-1* is education, we also presented a review of the NASA Education Strategic Coordination Framework including the NASA Education Implementation Framework. The aspects of the *Fox-1* project that address the NASA education goals and outcomes were highlighted. The review panel was then asked for their comments, suggestions and an overall assessment of the merits of the *Fox-1* project.

- Was the merit review competitive or non-competitive?

The merit review was non-competitive.

- What were the qualifications of the merit review committee members?

The merit review panel included the following members (alphabetical order):

1. Mr. David Hinkley is the Project Leader, Mechanics Research Office of The Aerospace Corporation.
2. Dr. Allen Katz is a Professor of Engineering Science, College of New Jersey and President of Linearizer Technology, Inc. (LTI.)
3. Mr. Jan King is a distinguished space industry veteran with more than 40 years of experience including the development of 12 large and 17 small spacecraft and one launch vehicle.
4. Dr. Robert McGwier is the Director of Research, Hume Center for National Security and Technology and a Research Professor, Department of Electrical and Computer Engineering, Virginia Tech.

Please see APPENDIX 1 for resumes of the members of the review panel.

- What factors did the merit review use to assess merit?

The panel was asked to assess the educational aspects of the *Fox-1* project that were identified as supporting the goals and outcomes identified in the NASA Education Strategic Coordination Framework.

- What was the outcome of the merit review?

The merit review panel determined that the project "*nailed*" the education goals and that the project "*meets NASA needs and goes beyond.*" A panel member commented that AMSAT has a history of space education that is "*demonstrated better than just about any other organization.*" The review panel suggested that we should mention our past successes especially the ARISSat-1 and AO-51 satellites.

Another suggestion was that we should point out that in the classroom, only a teacher or an outside volunteer needs to have an amateur radio license to allow the students to make use of the satellite. They also recommended that we highlight that all of our telemetry and experiment data will be openly available on our server and has educational value for classroom use.

- How did the Respondent respond to and/or address the findings of the merit review?

We updated our plans to include mention of the additional educational benefits suggested by the review panel.

11 Feasibility Review

The AMSAT *Fox-1* team held a feasibility review. The review was conducted as an on-line, multimedia teleconference with key members of the *Fox-1* team and a review panel of academic and industry experts.

- What was the feasibility review process?

The AMSAT team presented a set of power point slides that provided key information about the technology, people, organization, processes, risks, progress, schedule and financial support. The review panel was asked for their comments, suggestions and an overall assessment of the feasibility and likelihood of success of the *Fox-1* project.

- What were the qualifications of the feasibility review committee members?

The feasibility review panel included the following members (alphabetical order):

1. Mr. David Hinkley is the Project Leader, Mechanics Research Office of The Aerospace Corporation.
2. Dr. Allen Katz is a Professor of Engineering Science, College of New Jersey and President of Linearizer Technology, Inc. (LTI.)
3. Mr. Jan King is a distinguished space industry veteran with more than 40 years of experience including the development of 12 large and 17 small spacecraft and one launch vehicle.
4. Dr. Robert McGwier is the Director of Research, Hume Center for National Security and Technology and a Research Professor, Department of Electrical and Computer Engineering, Virginia Tech.

Please see APPENDIX 1 for resumes of the members of the review panel.

- What factors did the feasibility review use to assess feasibility?

The review panel assessed the *Fox-1* project according to the following factors:

1. Technology and technical approach
2. Engineering process
3. People and project organization
4. Major risks and mitigation
5. Progress to date
6. Remaining development and schedule
7. Project financial requirements and support

- How were the management team roles, experience, expertise, and the organizational structure of the team assessed?

The reviewers noted that the tremendous depth and breadth of experience on the *Fox-1* team far exceeds that of a typical CubeSat project. They also noted that although the all-volunteer staff was identified as the major project schedule risk, AMSAT has been doing satellite development this way for 40 years and has never missed a launch.

- How was the technical development risk associated with the overall CubeSat mission assessed?

The review panel was satisfied that we had addressed the major risks.

- If the CubeSat investigation requires critical technology development for flight readiness, how were the areas assessed, and how were the plans for completing technology development assessed?

Fox-1 does not depend on any critical technology development for flight readiness.

- Concerning the development of the CubeSat for flight, how was the probability of success assessed?

The review panel assessment was that the project has a very high probability of success. They noted that AMSAT has an excellent record of accomplishment and that the people working on the team have substantial experience.

- What was the outcome of the feasibility review?

The review panel, while noting the high probability of success, offered a few suggestions for improvement. A key suggestion was to move our Critical Design Review to after the engineering prototype is completed. This would allow the developers to address any problems found prior to construction of the flight models.

- How did Respondent respond to and/or address the findings of the feasibility review?

This proposal as submitted reflects all of the improvements suggested by the review panel.

- Is there sufficient financial support for the development of the CubeSat payload and for all other costs incurred by Respondent to support its participation in the project?

AMSAT has committed to fully funding the Fox-1 project. A letter of financial support from the AMSAT treasurer is included in APPENDIX 2.

Summary

In February 2012, NASA notified AMSAT that our *Fox-1* proposal was accepted! Out of 43 proposals submitted, NASA accepted 33 CubeSats into the program with *Fox-1* being given priority number 14.

¹ The NASA Strategic Plan can be found at <http://www.nasa.gov/news/budget/>

² The NASA Education Strategic Coordination Framework can be found at http://www.nasa.gov/offices/education/performance/strategic_framework.html

AMSAT Fox-1 Systems Engineering Documentation

By Jerry Buxton, N0JY
Fox-1 Systems Engineer
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The AMSAT Fox program introduced a new engineering process for AMSAT in which engineering documentation is provided at each stage of development. We are archiving all of this documentation on an on-line, backed-up, version control server. When the satellite has been completed, we will have an archive of traceable documentation. This can serve as the basis for planning and executing future satellite programs and can be updated to apply the lessons learned of what went well and what did not.

AMSAT is a truly unique organization in that we are a non-profit corporation that manufactures satellites using a geographically distributed, all-volunteer engineering staff. There are no common or established guidelines to cover our situation. As such, the Fox program engineering practices are themselves a work in progress. The practices used are drawn from industry sources, especially NASA¹ and IEEE.

AMSAT has adopted a common industry scheme known as *numbered* requirements. Each individual requirement has a unique number assigned to it. The number allows a very precise reference to a specific requirement and this enhances the overall traceability of the specifications. Design documents use these references to show which module or subsystem is responsible and how they are meeting each of the requirements. The requirements are tracked throughout the documents using requirements tracking software, from the ConOps down to the test results, in order to verify that all requirements are properly implemented.

Due to US State Department ITAR² restrictions, our document server is only available to project members who have been vetted to meet the requirements for a "US-person." AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, this must be done in a specific way to meet the ITAR requirements. The information must first be released via an openly available publication.

We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per ITAR. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While the Concept of Operations (ConOps) and System Requirements Specification were published in the *Proceedings of the AMSAT-NA 29th Space Symposium and AMSAT-NA Annual Meeting*, the System Requirements Specification has undergone changes and will be reproduced in these Space Symposium proceedings.

In addition these proceedings will also present new engineering documents including the System Design Specification, Experiment Payload Requirements, IHU to RF System Interface Control Document, IHU to PSU Interface Control Document, IHU to Battery Interface Control Document, IHU to Attitude Determination Experiment Interface Control Document, and IHU Software Architecture Specification. An introduction to each of these documents follows.

The System Requirements Specification is a document that provides the top level technical specifications derived from the ConOps. This document describes what the system should do. The inputs, outputs, functions, mass, volume, environment and other external characteristics are included and specified in the system requirements. The level of detail for each requirement is specifically chosen to provide a clear definition of what the systems will do without too much specific detail or declaring how it will be done. This allows the engineers latitude in designing the best approach to satisfying the requirement.

The Avionics System Design Specification is a document that does provide specific details of how the system will be designed. The specifications are based on best design choices determined by the teams. The signals, connections, connectors, volume, and requirements specific to each system are stated in this document so that each system will fit together and function with the other systems.

The Experiment Payload Requirements are a smaller level of system requirements written specifically for the Penn State student designed attitude determination system. While the actual system designed by the students was not constructed before their graduation, the experiment payload system design itself will be incorporated onto the IHU board and this document describes the necessary functions of the system although revised to remove the physical requirements of a separate printed circuit board.

The Interface Control Documents (ICD) for the IHU to RF System, IHU to PSU, IHU to Battery, and IHU to Attitude Determination Experiment set the requirements for connections and communication between the IHU and the various systems. Each of the systems sends telemetry measurements and other signals to the IHU. The IHU sends telemetry audio and control signals to the RF System. The ICD allows the systems teams to work independently, knowing that their systems will interface successfully.

The IHU Software Architecture Specification provides the design specifications needed for the software design and operation of the Internal Housekeeping Unit.

The engineering documents published in these proceedings are what was available at time needed for inclusion and are intended to be interesting and informative. They may have changed since publication. AMSAT intends to continue to make the majority of the final technical documents, exclusive of satellite control information, available in future publications.

Some other documents are included in these proceedings because they contain additional information about Fox-1 that may be of interest to our members.

Also included here are Antenna Details showing the EZNEC 5.0+ models of the 2 meter and 70 centimeter antennas used on the satellite. Thank you to David Ping, WB6DP.

The IHU Software Components is included to show a breakdown of the software systems that were developed and written for the STMicroelectronics STM32L151 ultra-low-power 32-bit MCU, used for the IHU. Thank you to Bill Reed NX5R.

The Fox-1 Downlink Power Amplifier is a presentation of the findings during the prototype testing of the 2 meter PA that will be used for RF downlink. Thank you to Marc Franco, N2UO.

Receiving FOX-1 Satellite on 2 meters is a link budget for the 2 meter downlink based on the 400 mW (minimum) output of the Fox-1 power amplifier. Thank you to Tony Monteiro, AA2TX.

The Fox-1 Experimental Payload document is an IEEE presentation of their experiment given by the Penn State students. Thank you to Mike Corona, Brandon Marvenko, and Edward Pizzella.

¹ NASA Systems Engineering Handbook, NASA/SP-2007-6105 Rev1

² International Traffic in Arms Regulations, see:
http://www.pmddtc.state.gov/regulations_laws/itar_official.html

Date: September 4, 2012

Version: Version 1.12

AMSAT *Fox-1*

System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project. This 1 Unit CubeSat is a part of the AMSAT Fox program and includes a subset of the technical capabilities envisioned for the overall program.

Fox-1 is specifically intended as a replacement for the failing AMSAT *Echo* (i.e. AO-51) satellite. *Echo* has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. Its FM repeater provides very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This so called "*EasySat*" mode is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events. *Fox-1* will not duplicate all of the features and modes of *Echo* but its primary mission is to provide an FM Transponder in order to allow continued access to this *EasySat* mode of communications.

In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

AMSAT *Fox-I*
System Requirements



1.1 Document History

DATE	VERSION	SUMMARY
October 5, 2011	1.0	From Draft E
October 8, 2011	1.01	Fix typos in sections 1.2 and 3.5
October 9, 2011	1.02	Add Requirements Tracking
October 23, 2011	1.03	Additional Requirements Tracking
February 21, 2012	1.04	Update Section 3 and Formatting changes
April 18, 2012	1.05	Correction in Section 4
April 22, 2012	1.06	Correct link in Section 1.4 item 2
April 29, 2012	1.1	Revised 3.12.3, 3.12.7, 3.12.8, 3.13.3, 3.13.4, figure 1 to remove RESET and add IHU OFF and IHU ON commands
August 2, 2012	1.11	Added hidden text for requirements tracking to be shown in System Design Specification
September 4, 2012	1.12	Added the previously missing "Table 6" label

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the satellite at the system (i.e. "black box") level. It is intended to be used by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity is *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-I*, Concept of Operations, Version 1.0, September 19, 2011
2. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers/cds_rev12.pdf
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)
4. ITU Radio Regulations, Edition of 2008. available from <http://www.itu.int/publ/R-REG-RR-2008/en>

2 General Requirements

2.1 CubeSat Requirements

- 2.1.1 The satellite shall meet the requirements specified in the CubeSat Design Specification Rev. 12.
- 2.1.2 The satellite shall meet the requirements specified in the NASA LSP-REQ-317.01 Revision Basic.
- 2.1.3 The satellite shall meet the requirements for a 1 unit (single) CubeSat.
- 2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.
- 2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2 Environmental Requirements

- 2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
- 2.2.2 The satellite shall be designed to operate in a 650 km, sun-synchronous, circular orbit.
- 2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

- 2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 RF Frequency Requirements

- 2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.
- 2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.
- 2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.
- 2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.
- 2.4.5 All satellite frequencies shall be coordinated with the IARU.

Note that the band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.5.5 If the battery fails, including a short-circuit condition, the satellite shall continue to operate using only the photovoltaic panel power when in sunlight.

3.6 Experiment

- 3.6.1 The satellite shall provide current limited DC power for an experiment payload.
- 3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.
- 3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.

Note that the experiment payload will be specified in a separate document.

3.7 RF Uplink

- 3.7.1 The satellite shall include an FM uplink receiver.
- 3.7.2 The receiver shall have specifications as shown in Table 1.

Table 1

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ± 2.5 kHz (min.)

3.8 RF Downlink

- 3.8.1 The satellite shall include an FM downlink transmitter.
- 3.8.2 The transmitter shall have specifications as shown in Table 2.

Table 2

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9 FM Transponder

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 The transponder shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 The downlink transmitter shall be keyed (*i.e. PTT-on*) for 2 minutes following detection of the 67 Hz CTCSS tone.

3.9.4 The downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.

3.9.5 The 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 If the downlink transmitter has been un-keyed for a period of 5 minutes, the satellite shall send " HI THIS IS AMSAT FOX " in Morse code via a keyed audio tone on the downlink transmitter.

3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Table 3

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include calculated parameters as shown in Table 4.

AMSAT Fox-I
System Requirements



Table 4

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

Note that the telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

3.11.1 The satellite shall send telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall include experiment data.

3.12 Command Capability

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Table 5

Command	Operation
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

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- 3.12.4 A TEST command shall cause the satellite to respond by sending " TEST TEST TEST " in Morse code via a keyed audio tone on the RF downlink.
- 3.12.5 An INHIBIT command shall cause the satellite to cease RF transmissions.
- 3.12.6 Any command other than INHIBIT shall remove a transmit inhibit condition.
- 3.12.7 An IHU OFF command shall cause the IHU System to power off.
- 3.12.8 An IHU ON command shall cause the IHU System to power on.
- 3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.
- 3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.
- 3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

Note that the control interface will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Table 6

Name	Description
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder and telemetry active
Command Mode	Telemetry active, no FM transponder

3.13.2 The satellite shall transition between modes as shown in Figure 1.

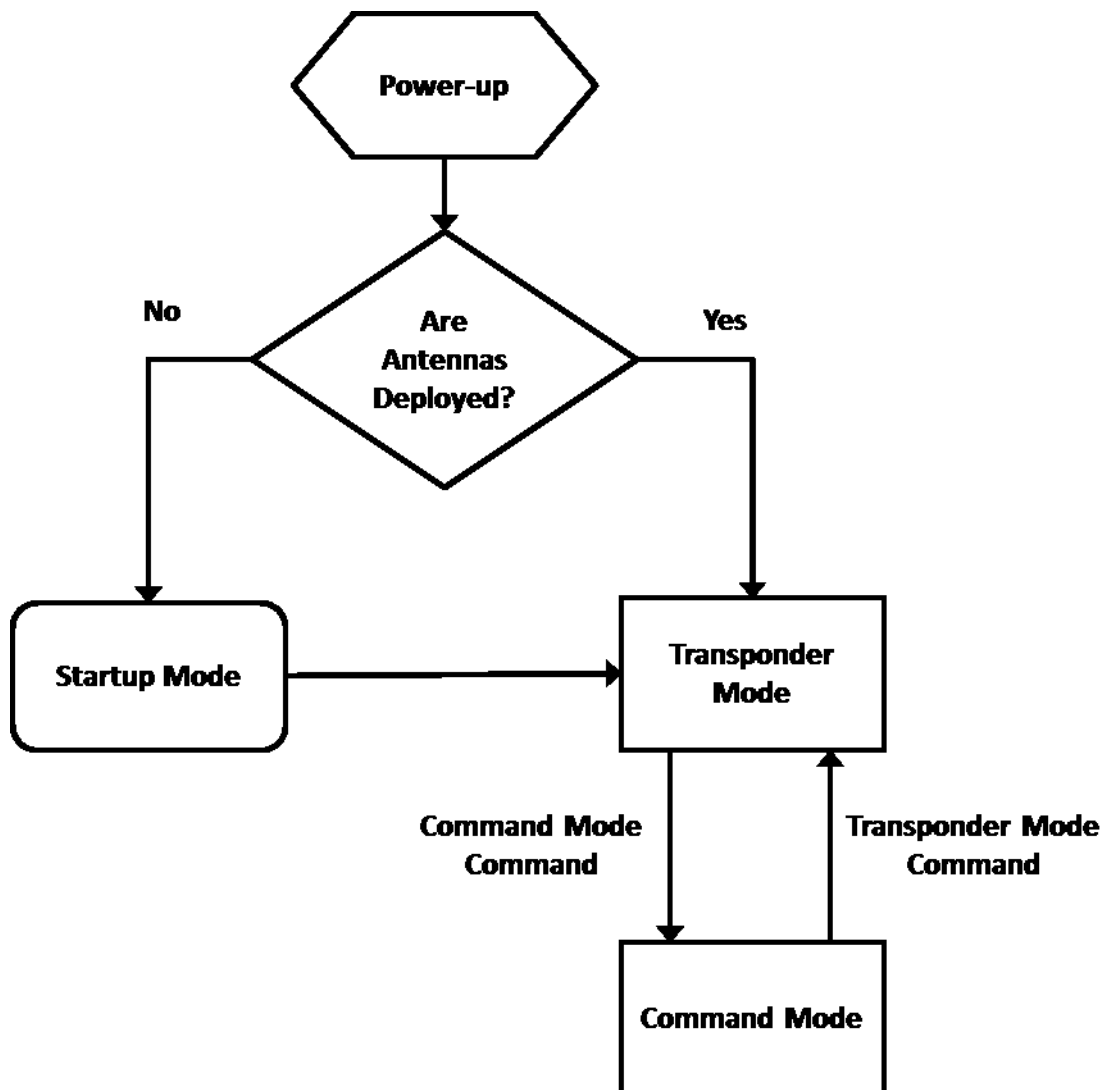


Figure 1. On-Orbit Operating Modes

- 3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.
- 3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up " state as shown in Figure 1.
- 3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.
- 3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.
- 3.13.7 In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas and then enter Transponder Mode.
- 3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.
- 3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. (*i.e. signals that appear on the uplink shall not be repeated on the downlink.*)
- 3.13.10 If another Command Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Command Mode.
- 3.13.11 The RF uplink shall be monitored for commands in all modes.

4 External Interface Documents

To fully specify the satellite technical requirements, the following documents must also be provided;

- 1. IARU Coordinated Frequency Plan
- 2. Telemetry Interface Specification
- 3. Control Interface Specification
- 4. Experiment Payload Specification

5 Summary

The *Fox-1* satellite will be AMSAT's first CubeSat. Its primary mission is to provide an FM Transponder communications capability. The secondary mission is to host a university-provided experiment payload.

Date: September 30, 2012

Version: 3.14

AMSAT *Fox-1*

Avionics System Design Specification

1 Introduction

This document contains the system level design specifications for the AMSAT *Fox-1* satellite avionics systems. It is driven by the System Requirements Specification and other documents provided by the developers of the individual systems that make up the satellite system.

1.1. Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	From Draft F
April 9, 2012	1.1	Add signal characteristics, update bus pin connections per System Team input
April 17, 2012	1.2	Add external connector specification in sections 2.6, 2.12 and 2.14 and references in section 6
April 18, 2012	1.21	Add MMCX connectors gender
April 22, 2012	1.3	Minor corrections in signal characteristics, remove +Z antenna deploy and sensor connections
July 10, 2012	2.0	Many revisions from PDR
July 11, 2012	2.01	One RBF pin removed from bus pin assignments, updated 2.1 interconnect diagram, updated 2.1 signal characteristics
July 21, 2012	2.1	Revised bus signals, bus pin assignments Updated RF block diagram
July 22, 2012	2.11	Revision to some RF signal descriptions, change antenna/coax connectors to UMCC type, updated RF block diagram, added driving and load system columns to signal characteristics
September 9, 2012	3.0	Major changes.
September 11, 2012	3.01	Defunct IHU block diagram pending update
September 12, 2012	3.1	Added PCB volume requirements
September 23, 2012	3.11	Change TX PTT to RX PTT, -Z Deploy switches to TX, update figures and tables accordingly
September 26, 2012	3.12	Update bus and pin assignment drawings
September 27, 2012	3.13	Update bus pin assignment drawings
September 30, 2012	3.14	Update RF block diagram to remove ITAR notice

1.2. Document Scope

The purpose of this document is to specify the avionics systems and their connections to each other and to external components for the satellite. It is intended to be used by the hardware, software, and mechanical designers to develop the architecture and interconnections for the satellite avionics systems.

1.3. Document Format

This document provides these elements in a numbered format. The numbered sections specify each major system in the satellite while numbered items for each system specify the external connections required and the number of lines for each connection. Satellite bus and external connections are further described in figures and tables.

Where System Requirements are reproduced their numbers are from the AMSAT *Fox-1* System Requirements Specification.

1.4. References

1. AMSAT *Fox-1* ConOps
2. AMSAT *Fox-1* System Requirements Specification
3. AMSAT *Fox-1* Bus Signal Connections Diagram
4. AMSAT *Fox-1* Bus Pin Assignment
5. AMSAT *Fox-1* Avionics System Design Specification Spreadsheet
6. AMSAT FOX-ME-112_PCB_ASSY.pdf
7. AMSAT FOX-ME-114_BATTERY_ASSY.pdf

AMSAT Fox-1
Avionics System Design Specification



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Figure 1: Interconnect Diagram

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Avionics System Design Specification



Table 1: System Bus Signal Characteristics

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
1	SPI1 NSS	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
3	SPI1 SCK	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
4	TX PA Temperature	Analog	100-2000 mV	TX	30 - 60 kΩ	IHU	Analog Devices TMP36F
5	SPI1 MISO	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
6	TX Osc Temperature	Analog	100-2000 mV	TX	30 - 60 kΩ	IHU	Analog Devices TMP36F
7	SPI1 MOSI	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
8	RX Osc Temperature	Analog	100-2000 mV	RX	30 - 60 kΩ	IHU	Analog Devices TMP36F
9	Serial RXD	Digital	3.0 V	EXP 1-4		IHU	TTL, Async, Mark High
10	*RESERVED*						
11	Serial TXD	Digital	3.0 V	IHU		EXP 1-4	TTL, Async, Mark High
12	IHU Audio 1 Out	Analog	2 V p-p audio	IHU	600 Ω, Unbalanced	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
13	Experiment Enable 1	Digital		IHU		EXP 1-4	HIGH = Enable EXP 1
14	IHU Audio 2 Out	Analog	N/A	IHU	N/A	TX	*RESERVED FOR FUTURE USE*
15	Experiment Enable 2	Digital		IHU		EXP 2	HIGH = Enable EXP 2
16	RX Command Data 8	Digital		RX		IHU	
17	Experiment Enable 3	Digital		IHU		EXP 3	HIGH = Enable EXP 3
18	RX Command Data 9	Digital		RX		IHU	
19	Experiment Enable 4	Digital		IHU		EXP 4	HIGH = Enable EXP 4
20	RX Command Data 10	Digital		RX		IHU	
21	*RESERVED*						
22	RX Command Data 11	Digital		RX		TX	
23	I ² C1 SCL	Digital	Note ¹	IHU			I ² C Standard, IHU Master
24	RX Command Strobe	Digital		RX	30 - 60 kΩ	IHU	
25	I ² C1 SDA	Digital	Note ¹	IHU			I ² C Standard, IHU Master
26	COMMAND Mode	Digital		IHU		TX	HIGH = Command Mode
27	*RESERVED*						
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT
29	*RESERVED*						
30	RX PTT	Digital		TX	30 - 60 kΩ	IHU	HIGH = HANG TIMER ACTIVE
31	*RESERVED*						
32	RX CD	Digital		RX	30 - 60 kΩ	IHU	
33	*RESERVED*						
34	RX Audio 1	Analog	2 V p-p audio	RX	600 Ω, Unbalanced	IHU	10 Hz - 7 kHz bandwidth
35	*RESERVED*						
36	RX Audio 2	Analog	N/A	RX	N/A	IHU	*RESERVED FOR FUTURE USE*
37	I ² C2 SCL	Digital	Note ¹	IHU		PSU	I ² C Standard, IHU Master
38	Comp Lim	Analog	1.4 VDC	RX	100 kΩ	TX	
39	I ² C2 SDA	Digital	Note ¹	IHU		PSU	I ² C Standard, IHU Master
40	RBF 1	Analog	N/A	RBF	N/A	PSU	N.O. for operation
41	+Z Thermistor	Analog	N/A	EXT	N/A	PSU	NCP21XM472J03RA
42	RBF 2	Analog	N/A	RBF	N/A	PSU	N.O. for operation
43	-Z Thermistor	Analog	N/A	EXT	N/A	PSU	NCP21XM472J03RA
44	TX Antenna Deploy	Analog	TBR	IHU	TBR	PSU	Not designed yet
45	+Z CIC	Analog	0.1 - 3 VDC	EXT	N/A	PSU	
46	TX Antenna Sensor	Digital	N/A	IHU	N.O.	PSU	N.O. when deployed
47	-Z CIC	Analog	0.1 - 3 VDC	EXT	N/A	PSU	
48	RX Antenna Sensor	Digital	N/A	IHU	N.O.	PSU	N.O. when deployed
49	Umbilical USBP	Digital		USB		IHU	USB Standard
50	RX Antenna Deploy	Analog	TBR	IHU	TBR	PSU	Not designed yet
51	Umbilical USBM	Digital		USB		IHU	USB Standard
52	-Z Deploy Switches	Analog	N/A	EXT	N/A	PSU	TBR - (N.O. = OPERATE?)
53	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
54	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
55	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
56	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
57	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
58	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
59	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
60	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	

Note¹ All SPI and I²C signals are 3.0 V levels

All Digital signals are CMOS logic levels high impedance load unless otherwise noted

AMSAT Fox-1 Avionics System Design Specification



September 27, 2022
Version 2.15

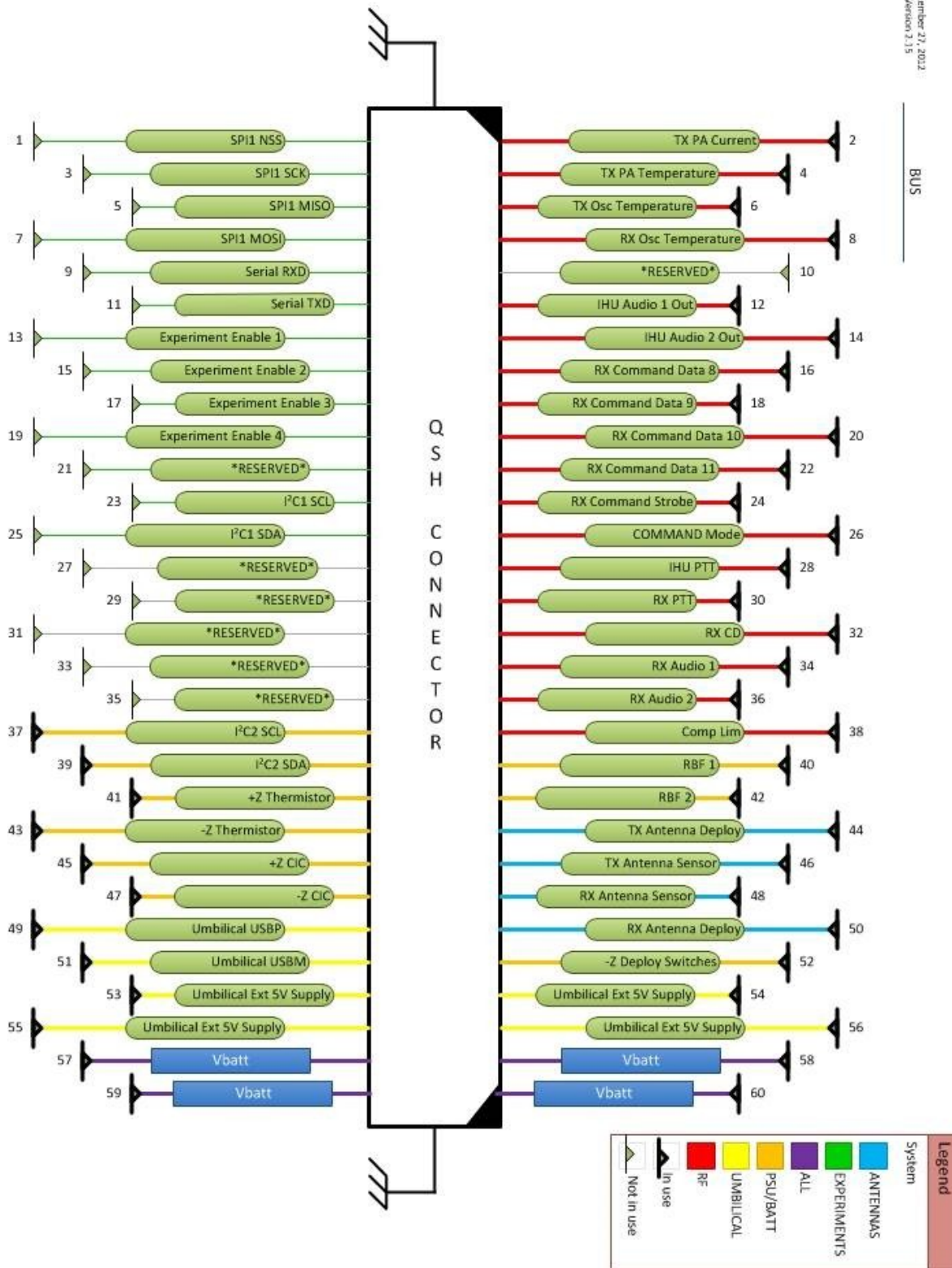


Figure 2: Complete Bus Connection Pin Assignments

3 RF Transmitter System

3.1 System Requirements Applicable to RF Transmitter System

- 2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
- 2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.
- 2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
- 2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.
- 2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.
- 2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.
- 2.4.5 All satellite frequencies shall be coordinated with the IARU.
- 3.8.1 The satellite shall include an FM downlink transmitter.
- 3.8.2 The transmitter shall have specifications as shown in Table 2.

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

- 3.8.3 The transmitter shall provide a means to prevent over modulation.
- 3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.
- 3.9.2 The transponder shall detect the presence of a 67 Hz CTCSS tone on the uplink.
- 3.9.3 The downlink transmitter shall be keyed (i.e. PTT-on) for 2 minutes following detection of the 67 Hz CTCSS tone.
- 3.9.4 The downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.
- 3.9.5 The 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.
- 3.9.6 If the downlink transmitter has been un-keyed for a period of 5 minutes, the satellite shall send " HI THIS IS AMSAT FOX " in Morse code via a keyed audio tone on the downlink transmitter.
- 3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.
- 3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.11.1 The satellite shall send telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Command	Operation
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

3.12.4 A TEST command shall cause the satellite to respond by sending " TEST TEST TEST " in Morse code via a keyed audio tone on the RF downlink.

3.12.5 An INHIBIT command shall cause the satellite to cease RF transmissions.

3.12.6 Any command other than INHIBIT shall remove a transmit inhibit condition.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Name	Description
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder and telemetry active
Command Mode	Telemetry active, no FM transponder

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.

3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)

3.2 Volume Requirements Applicable to RF Transmitter System

3.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5 mm from the -Z surface of the PC board.

3.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

3.3 Interface Control Documents Applicable to RF Transmitter System

[AMSAT *Fox-1* IHU to RF System Interface Control Document](#)

3.4 RF Transmitter System PCB Bus Connections

September 27, 2012
Version 2.15

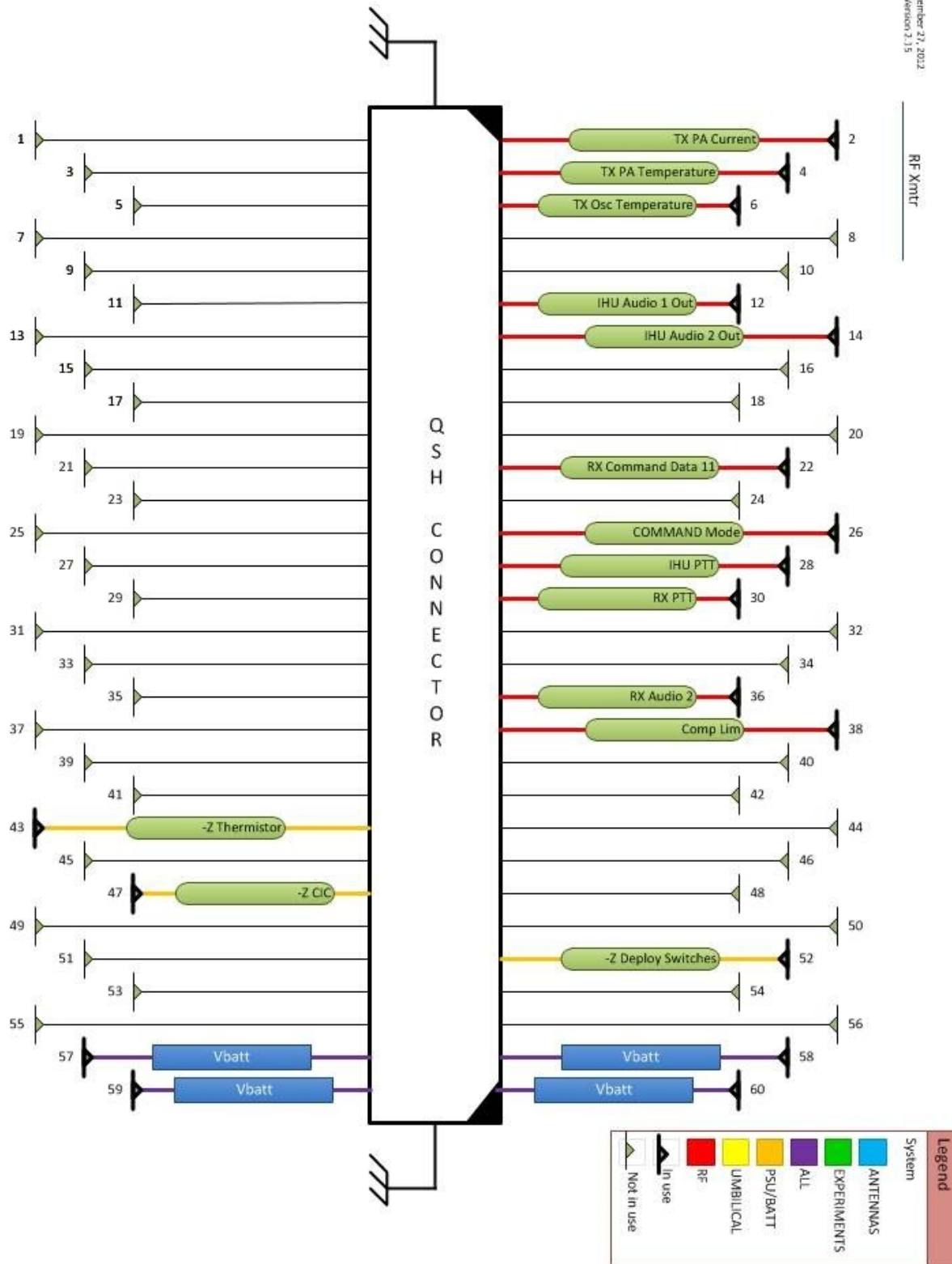


Figure 3: RF Transmitter System Bus Connection Pin Assignments

3.5 RF Transmitter System PCB External Connections

- 3.5.1 2 meter band RF output, coaxial cable to Transmit Antenna
- 3.5.2 Spacecraft deployment switches cable(s) TBR
- 3.5.3 Three connections via Samtec FSI-105-06-L-S-AD connector
 - 3.5.3.1 1 contact -Z Solar Panel Thermistor
 - 3.5.3.2 1 contact -Z Solar Panel CIC +
 - 3.5.3.3 1 contact common or - for above four connections

Table 2: External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	2 meter Antenna $\approx$ 145.9 MHz	RF	0 to +30 dBm	2 meter Antenna	50 Ω unbal.	N/A
Cable TBR	Spacecraft Deployment Switches	Analog	N/A	Switch	N/A	52

Table 3: -Z PCB face FSI-105-06-L-S-AD connector mates to pads on -Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	-Z Thermistor	Analog	N/A	N/A	N/A	PSU	43
2	-Z Deploy Switches	Analog	N/A	N/A	N/A	PSU	52
3	-Z Solar Panel Common						Ground Plane
4	N/C						
5	-Z CIC (+)	Analog	2.66 VDC nominal	N/A	N/A	PSU	47

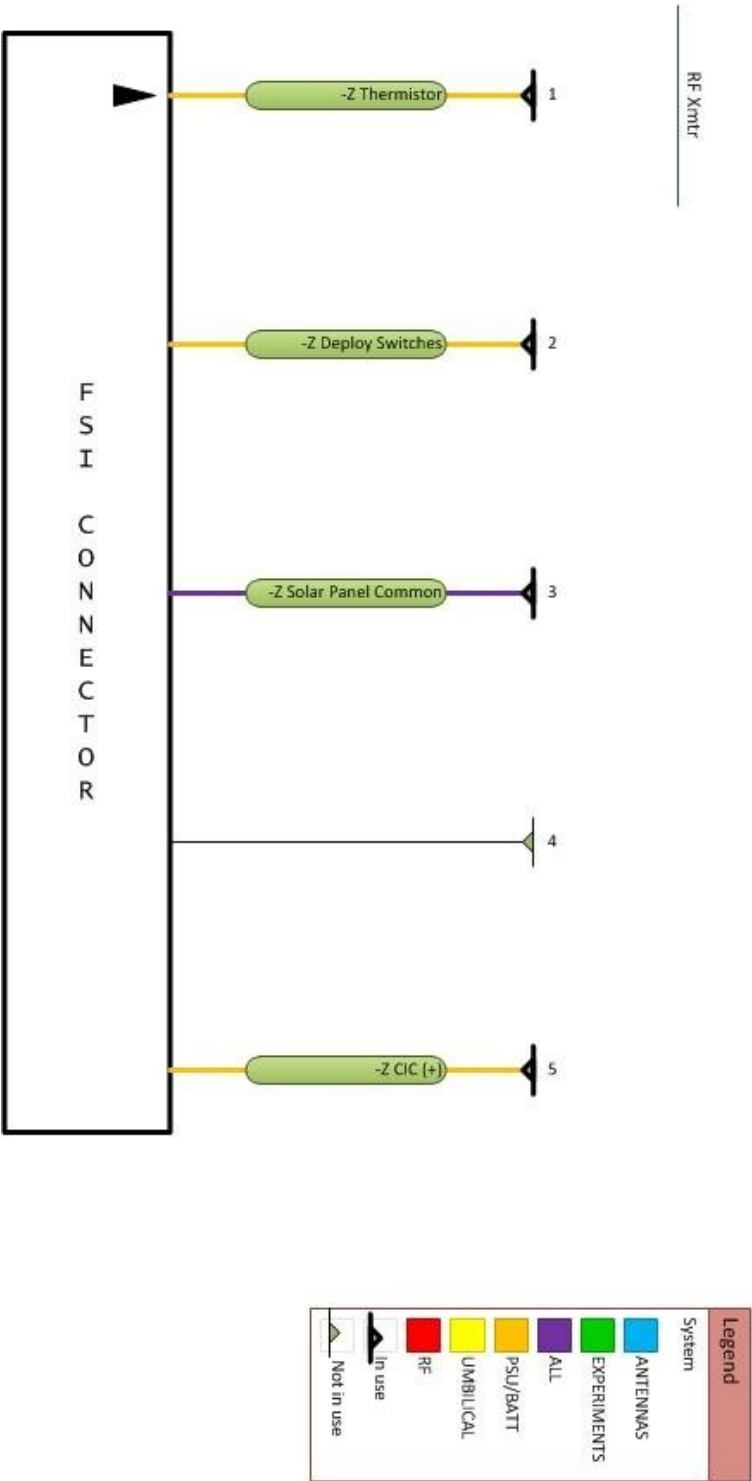


Figure 4: RF Transmitter System FSI-105-06-L-S-AD Connection Pin Assignments

4 RF Receiver System

4.1 System Requirements Applicable to RF Receiver System

- 2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
- 2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.
- 2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
- 2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.
- 2.4.5 All satellite frequencies shall be coordinated with the IARU.
- 3.7.1 The satellite shall include an FM uplink receiver.
- 3.7.2 The receiver shall have specifications as shown in Table 1.

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ± 2.5 kHz (min.)

- 3.8.3 The transmitter shall provide a means to prevent over modulation.
- 3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.
- 3.9.2 The transponder shall detect the presence of a 67 Hz CTCSS tone on the uplink.
- 3.9.4 The downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.
- 3.9.5 The 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.
- 3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.
- 3.10.1 The satellite shall collect telemetry data.
- 3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

- 3.10.3 The measured parameters shall be sampled at least every 15 seconds.
- 3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.
- 3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Command	Operation
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.

3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)

3.13.11 The RF uplink shall be monitored for commands in all modes.

4.2 Volume Requirements Applicable to RF Receiver System

4.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

4.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

4.3 Interface Control Documents Applicable to RF Receiver System

[AMSAT *Fox-1* IHU to RF System Interface Control Document](#)

4.4 RF Receiver System PCB Bus Connections

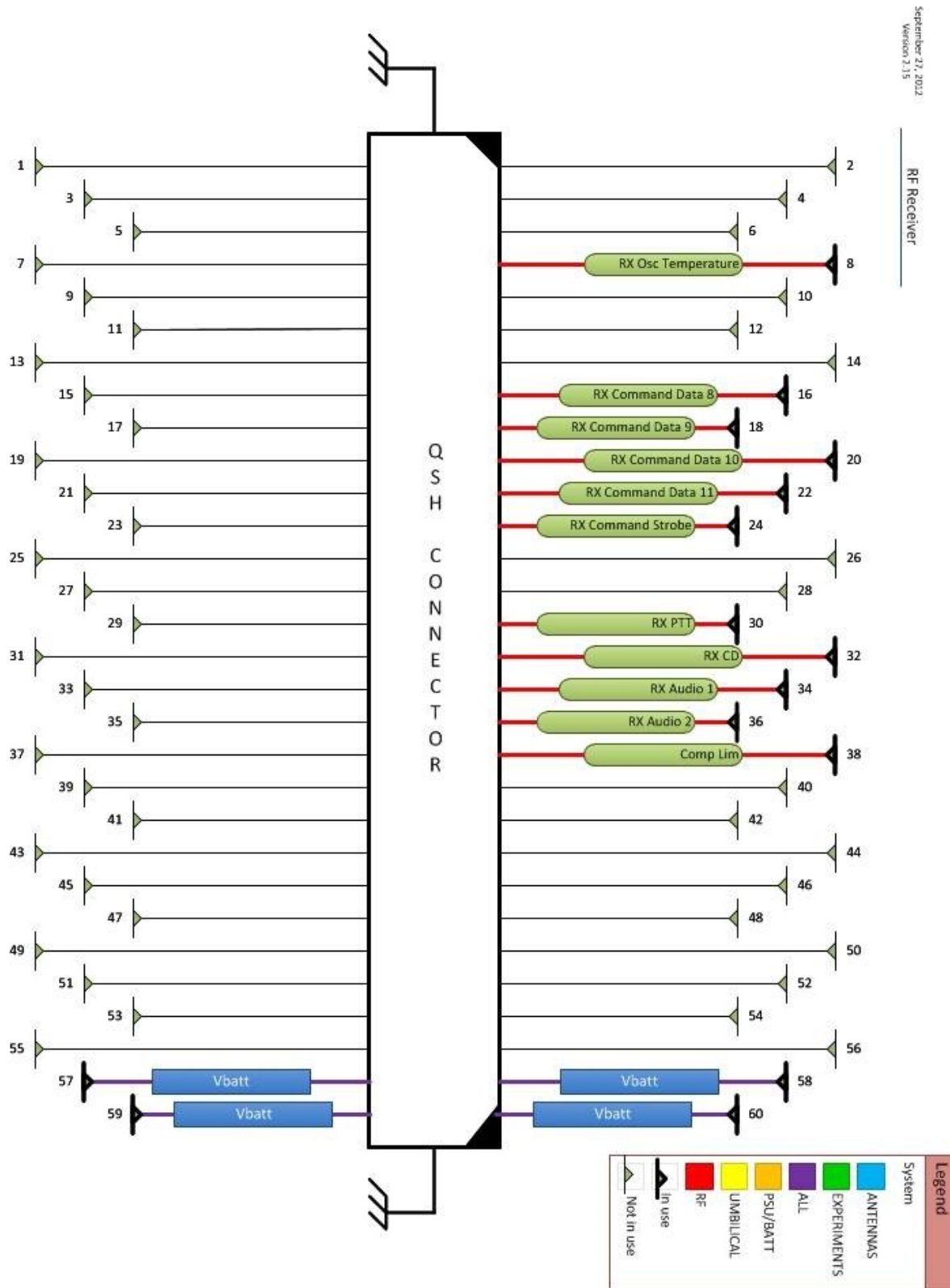


Figure 5: RF Receiver System Bus Connection Pin Assignments

4.5 RF Receiver System PCB External Connections

4.5.1 70cm band RF input, coaxial cable to Receive Antenna

Table 4: RF Receiver System External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/Power	Source System	Load Z	Bus Pin
Coaxial Cable	70 cm RF Input 437 MHz	RF	-60 dBm to -140 dBm	70 cm Antenna	50 Ω unbal.	N/A

5 Internal Housekeeping Unit (IHU) System

5.1 System Requirements Applicable to Internal Housekeeping Unit (IHU) System

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.

3.9.6 If the downlink transmitter has been un-keyed for a period of 5 minutes, the satellite shall send " HI THIS IS AMSAT FOX " in Morse code via a keyed audio tone on the downlink transmitter.

3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include calculated parameters as shown in Table 4.

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

3.11.1 The satellite shall send telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.11.4 The telemetry transmission shall include telemetry frames.

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3.11.5 The telemetry transmission shall include experiment data.

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.3 The following commands shall be provided, as shown in Table 5.

Command	Operation
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

3.12.4 A TEST command shall cause the satellite to respond by sending " TEST TEST TEST " in Morse code via a keyed audio tone on the RF downlink.

3.12.7 An IHU OFF command shall cause the IHU System to power off.

3.12.8 An IHU ON command shall cause the IHU System to power on.

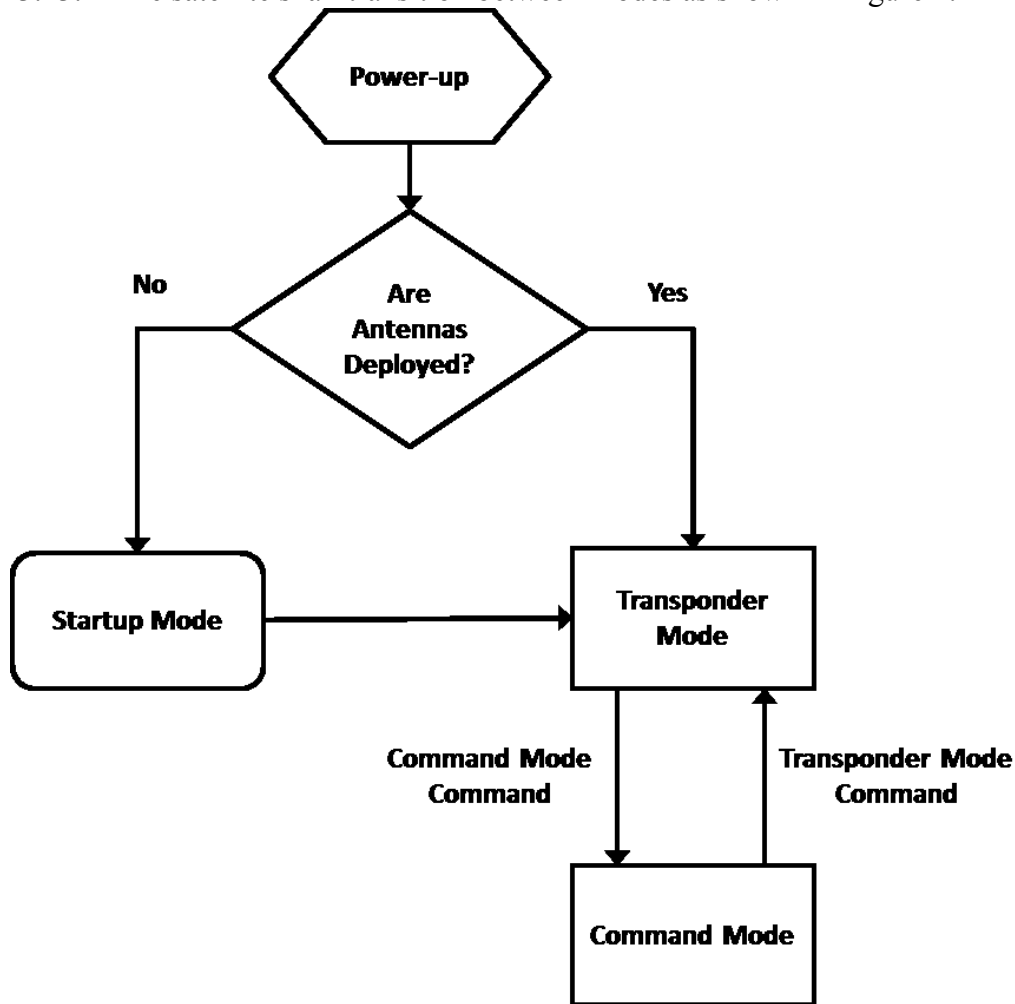
3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Name	Description
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder and telemetry active
Command Mode	Telemetry active, no FM transponder

3.13.2 The satellite shall transition between modes as shown in Figure 1.



3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.

3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up " state as shown in Figure 1.

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.

3.13.7 In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas and then enter Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.

3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)

3.13.10 If another Command Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Command Mode.

3.13.11 The RF uplink shall be monitored for commands in all modes.

5.2 Volume Requirements Applicable to IHU System

5.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

5.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

5.3 Interface Control Documents Applicable to IHU System

[AMSAT *Fox-1* IHU to RF System Interface Control Document](#)

[AMSAT *Fox-1* IHU to PSU Interface Control Document](#)

[AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document](#)

5.4 Internal Housekeeping Unit (IHU) System PCB Bus Connections

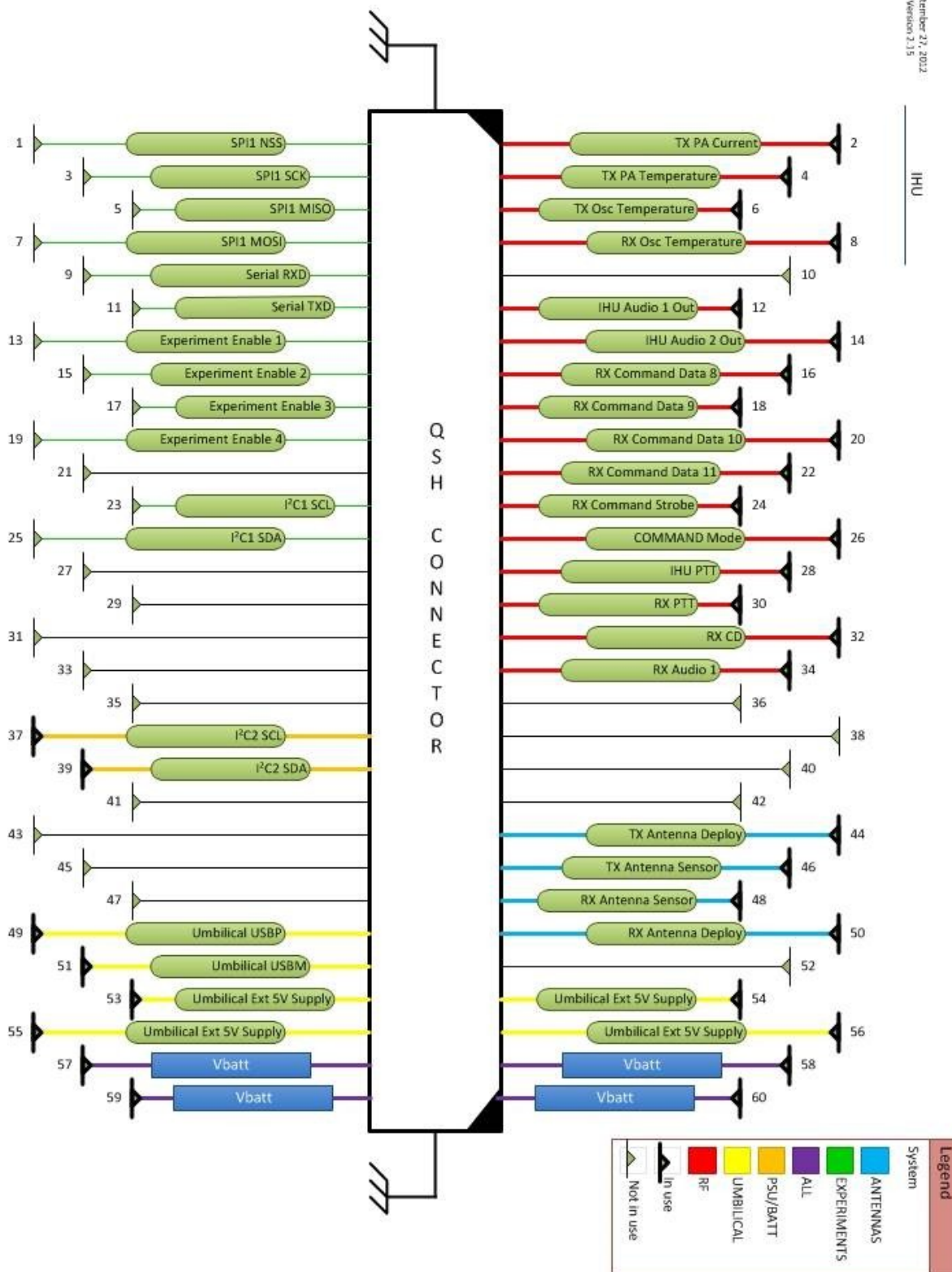


Figure 6: IHU System Bus Connection Pin Assignments

6 Power Supply System (PSU)

6.1 System Requirements Applicable to Power Supply System (PSU)

- 2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
- 2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.
- 2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
- 3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.
- 3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).
- 3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.
- 3.5.1 The satellite shall produce electrical power from sunlight.
- 3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.
- 3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.
- 3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.
- 3.5.5 If the battery fails, including a short-circuit condition, the satellite shall continue to operate using only the photovoltaic panel power when in sunlight.
- 3.6.1 The satellite shall provide current limited DC power for an experiment payload.
- 3.10.1 The satellite shall collect telemetry data.
- 3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

- 3.10.3 The measured parameters shall be sampled at least every 15 seconds.
- 3.10.5 The telemetry data shall also include calculated parameters as shown in Table 4.

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

6.2 Volume Requirements Applicable to PSU System

- 6.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

6.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 3.0 mm from the +Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 6.0 mm from the +Z surface of the PC board in the rest of the board area.

6.3 Interface Control Documents Applicable to PSU System
[AMSAT *Fox-1* IHU to PSU Interface Control Document](#)

6.4 Power Supply System (PSU) PCB Bus Connections

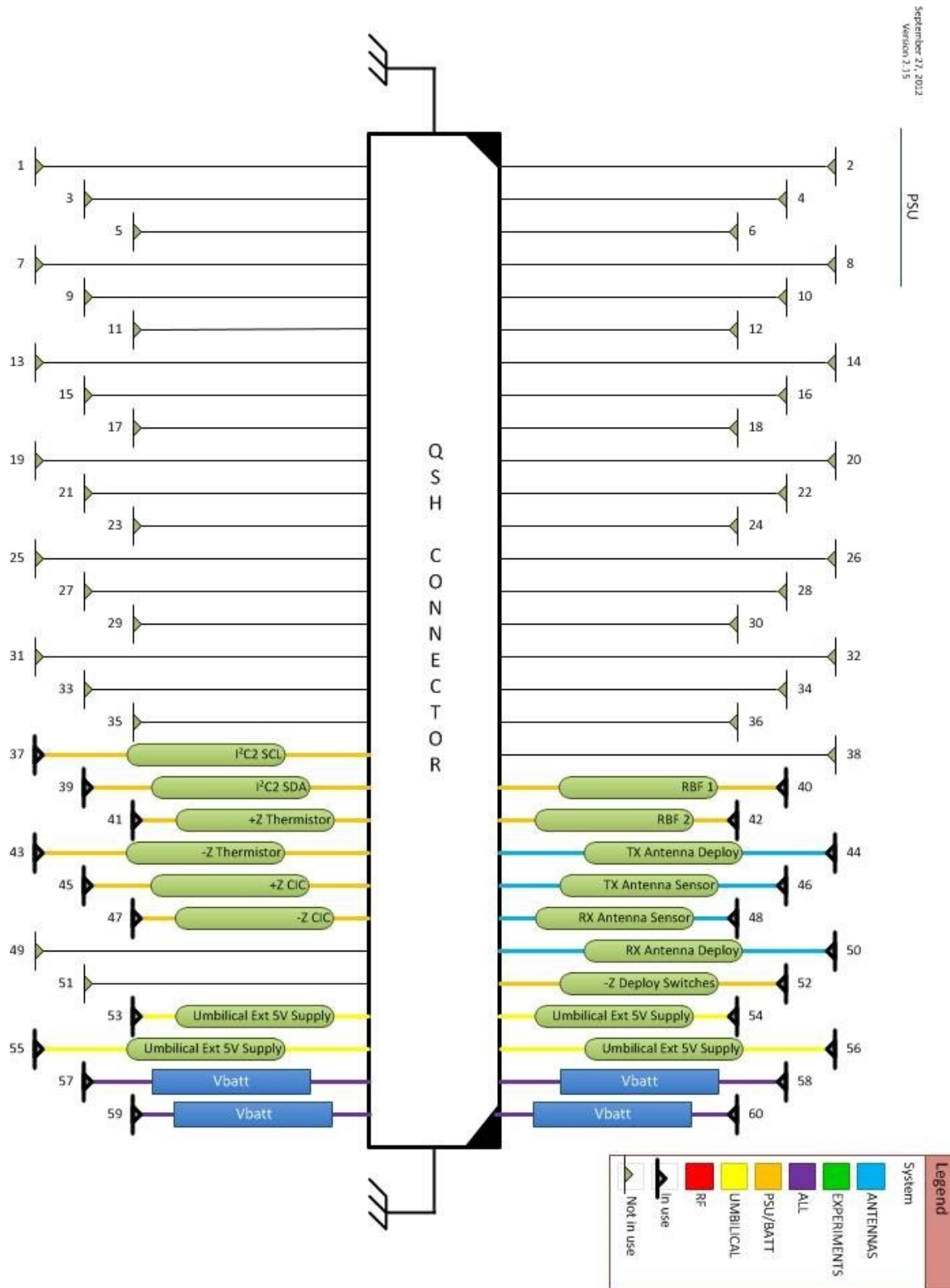


Figure 7: PSU Bus Connection Pin Assignments

6.5 Power Supply System (PSU) PCB External Connections

6.5.1 Three connections to +X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector

6.5.1.1 1 contact +X Solar Panel Thermistor

6.5.1.2 1 contact +X Solar Panel CIC +

6.5.1.3 1 contact common or - for above two connections

6.5.2 Three connections to -X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector

6.5.2.1 1 contact -X Solar Panel Thermistor

6.5.2.2 1 contact -X Solar Panel CIC +

6.5.2.3 1 contact common or - for above two connections

6.5.3 Five connections to +Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector

6.5.3.1 1 contact +Y Solar Panel Thermistor

6.5.3.2 1 contact +Y Solar Panel CIC +

6.5.3.3 1 contact TX Antenna Deploy

6.5.3.4 1 contact TX Antenna Sensor

6.5.3.5 1 contact common or - for above connections

6.5.4 Five connections to -Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector

6.5.4.1 1 contact -Y Solar Panel Thermistor

6.5.4.2 1 contact -Y Solar Panel CIC +

6.5.4.3 1 contact RX Antenna Deploy

6.5.4.4 1 contact RX Antenna Sensor

6.5.4.5 1 contact common or - for above connections

6.5.5 All PCB edges that connect to solar panel MEC1-105-02-L-D-NP-A connectors shall have contact pads on the PCB for all connector pins, whether connected to a trace or not.

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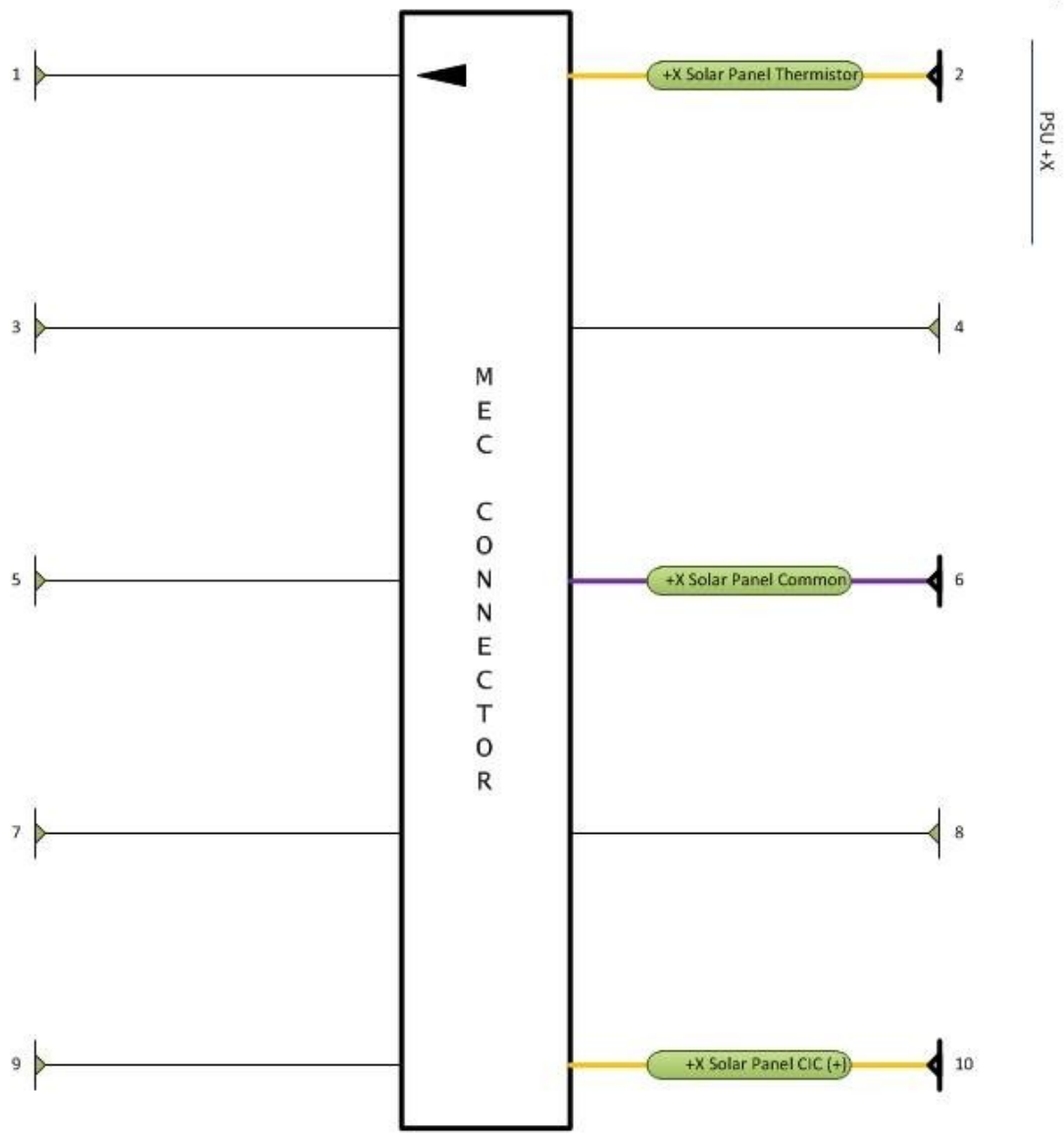
Table 5: +X PCB edge mates to MEC1-105-02-L-D-NP-A connector on +X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	+X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	+X Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

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September 23, 2012
Version 1.1



Legend	
System	
ANTENNAS	Blue square
EXPERIMENTS	Green square
ALL	Purple square
PSU/BAATT	Orange square
UMBILICAL	Yellow square
RF	Red square
In use	Black triangle pointing right
Not in use	Green triangle pointing left

Figure 8: PSU System +X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

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Table 6: -X PCB edge mates to MEC1-105-02-L-D-NP-A connector on -X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	-X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	-X Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

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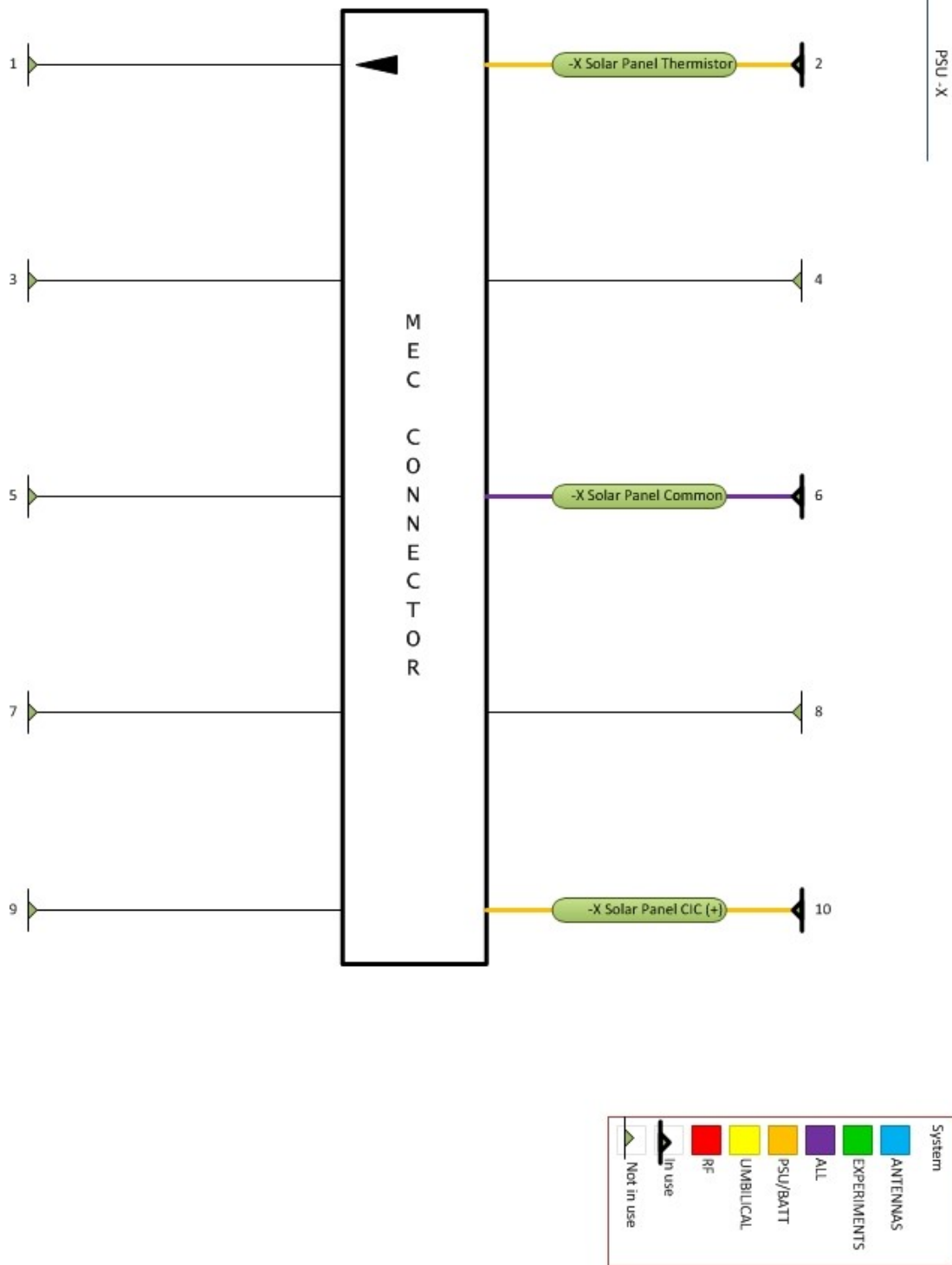


Figure 9: PSU System -X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

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Table 7: +Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on +Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	TX Antenna Sensor	Analog	N/A	IHU	N.O.	46
5	N/C					
6	+Y Solar Panel Common					Ground Plane
7	N/C					
8	TX Antenna Deploy	Analog	TBR	TBR	TBR	TBR
9	N/C					
10	+Y Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

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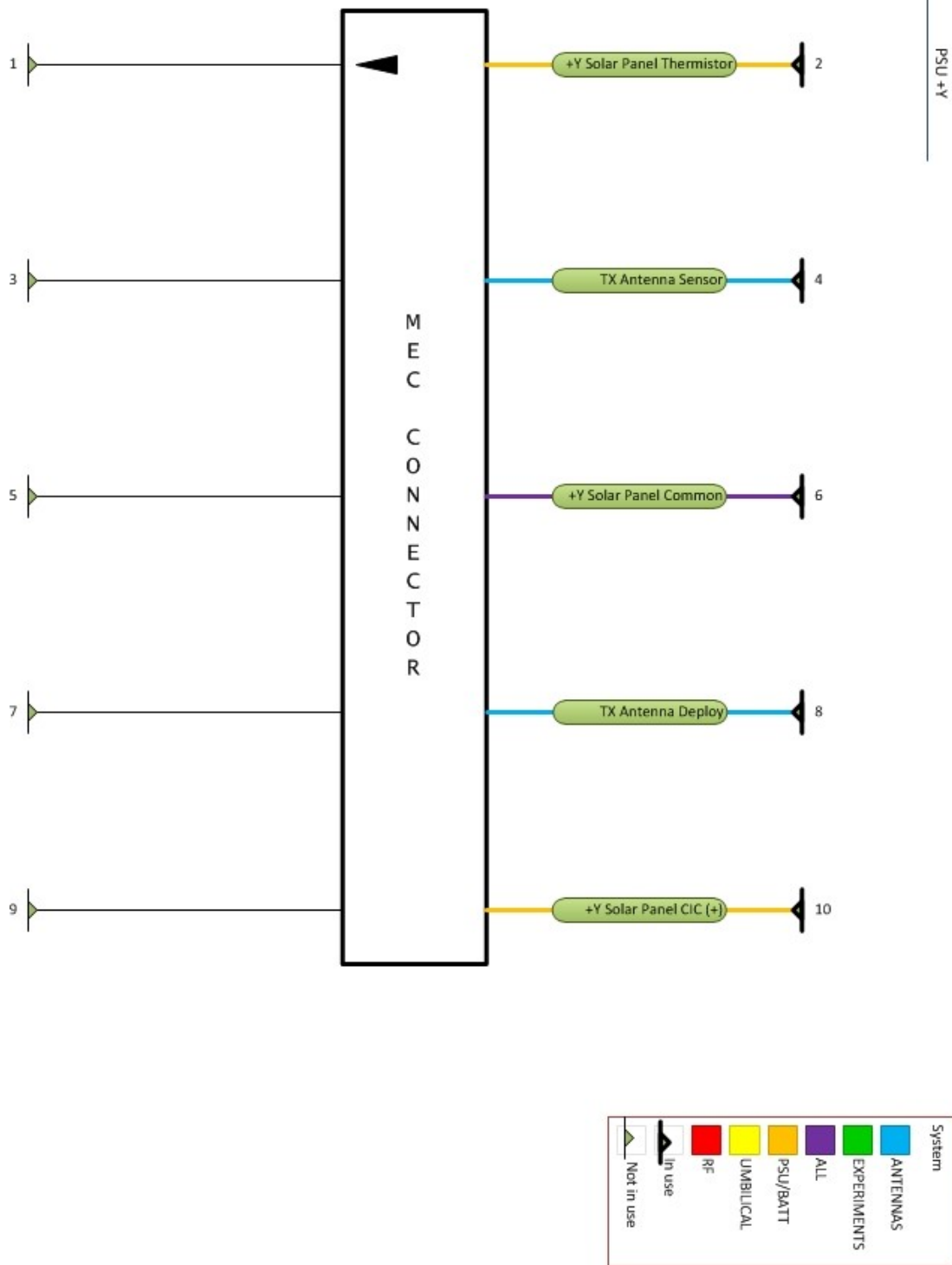


Figure 10: PSU System +Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

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Avionics System Design Specification



Table 8: -Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on -Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	RX Antenna Sensor	Analog	N/A	IHU	N.O.	48
5	N/C					
6	-Y Solar Panel Common					Ground Plane
7	N/C					
8	RX Antenna Deploy	Analog	TBR	TBR	TBR	TBR
9	N/C					
10	-Y Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

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Avionics System Design Specification

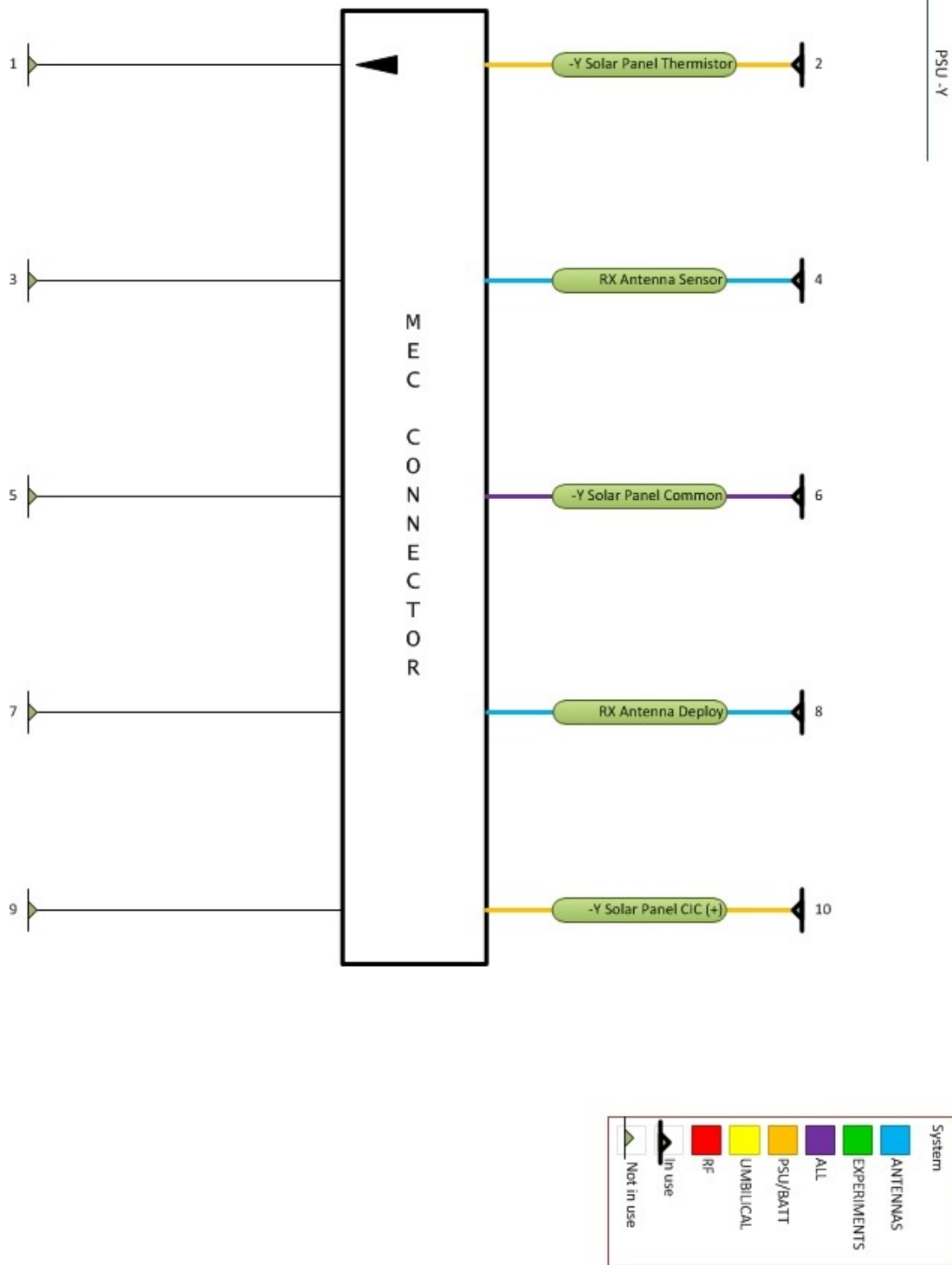


Figure 11: PSU System -Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

7 Battery System

7.1 Volume Requirements Applicable to Battery PCB 1 System

7.1.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 4.0 mm from the -Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 1.0 mm from the -Z surface of the PC board in the rest of the board area.

7.1.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 17.0 mm from the +Z surface of the PC board.

7.2 Battery PCB 1 System Bus Connections

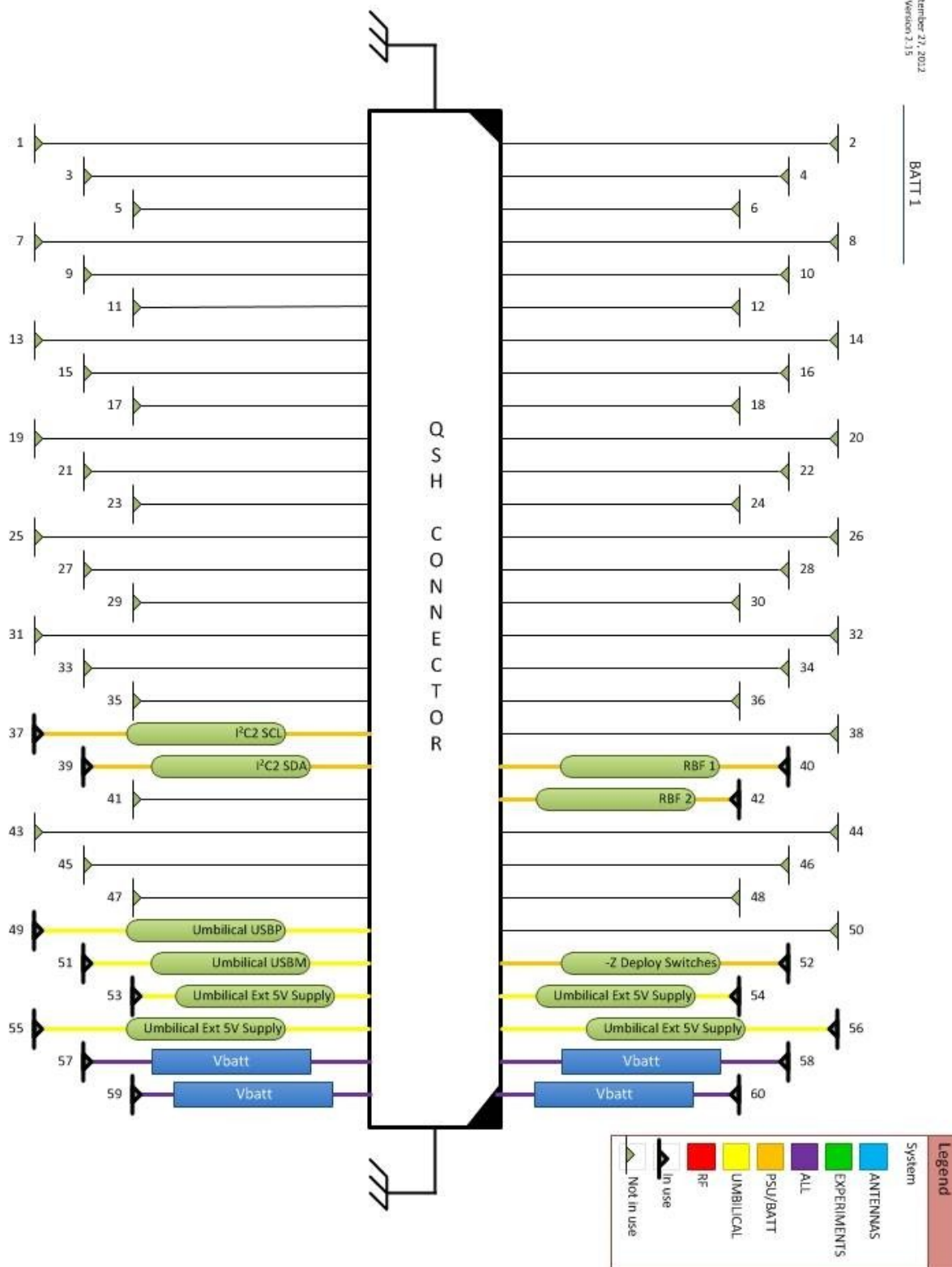


Figure 12: Battery 1 System Bus Connection Pin Assignments

7.3 Battery PCB 1 System External Connections

7.3.1 Umbilical as USB mini type B receptacle

7.3.2 Remove Before Flight as 3.5mm normally open TS jack

Table 9: Battery 1 External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/Power	Source System	Load Z	Bus Pin
USB 1	+5 VDC*	Analog	5 VDC	USB CONNECTOR	N/A	53, 54, 55, 56
USB 2	USB Data - (USBM)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	51
USB 3	USB Data + (USBP)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	49
USB 4	Ground			USB CONNECTOR	N/A	Ground Plane
RBF 1	RBF 1	Analog	N/A	3.5mm N.O. TS jack	N/A	40
RBF 2	RBF 2	Analog	N/A	3.5mm N.O. TS jack	N/A	42

*When external supply is connected to USB port

7.4 Battery PCB 2 System Bus Connections

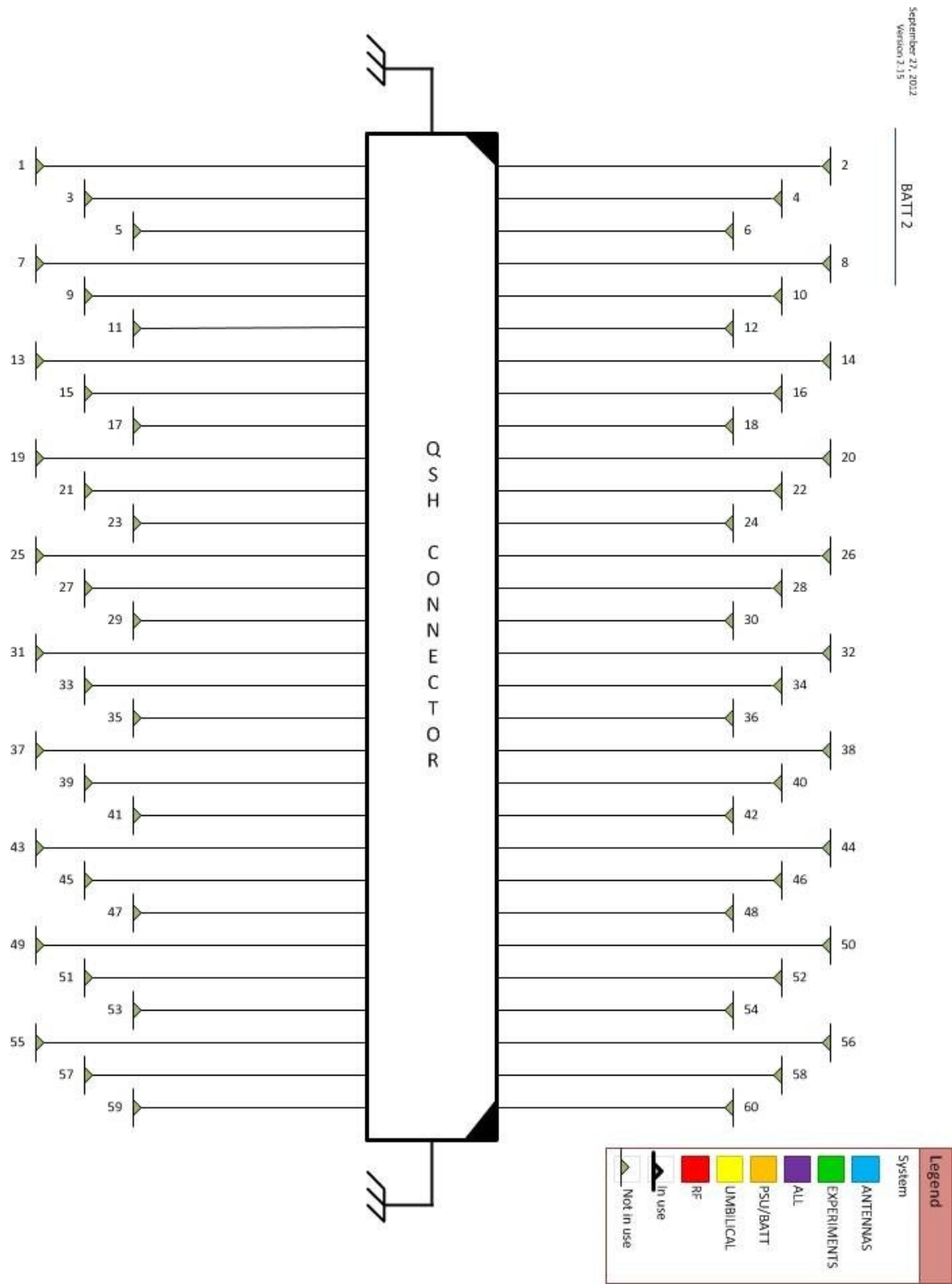


Figure 13: Battery 2 Bus Connection Pin Assignments

8 Experiment Payload Systems 1 through 4

8.1 System Requirements Applicable to Experiment Payload Systems 1-4

- 2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.
- 2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.
- 2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
- 2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.
- 2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
- 3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.
- 3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.

8.2 Volume Requirements Applicable to Experiment Payload System 1

8.2.1 No components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall protrude from the -Z surface of the PC board.

8.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.3 Volume Requirements Applicable to Experiment Payload Systems 2 and 3

8.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

8.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.4 Volume Requirements Applicable to Experiment System 4

8.4.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

8.4.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5.0 mm from the +Z surface of the PC board.

8.5 Experiment Payload 1-3 Systems PCB Bus Connections

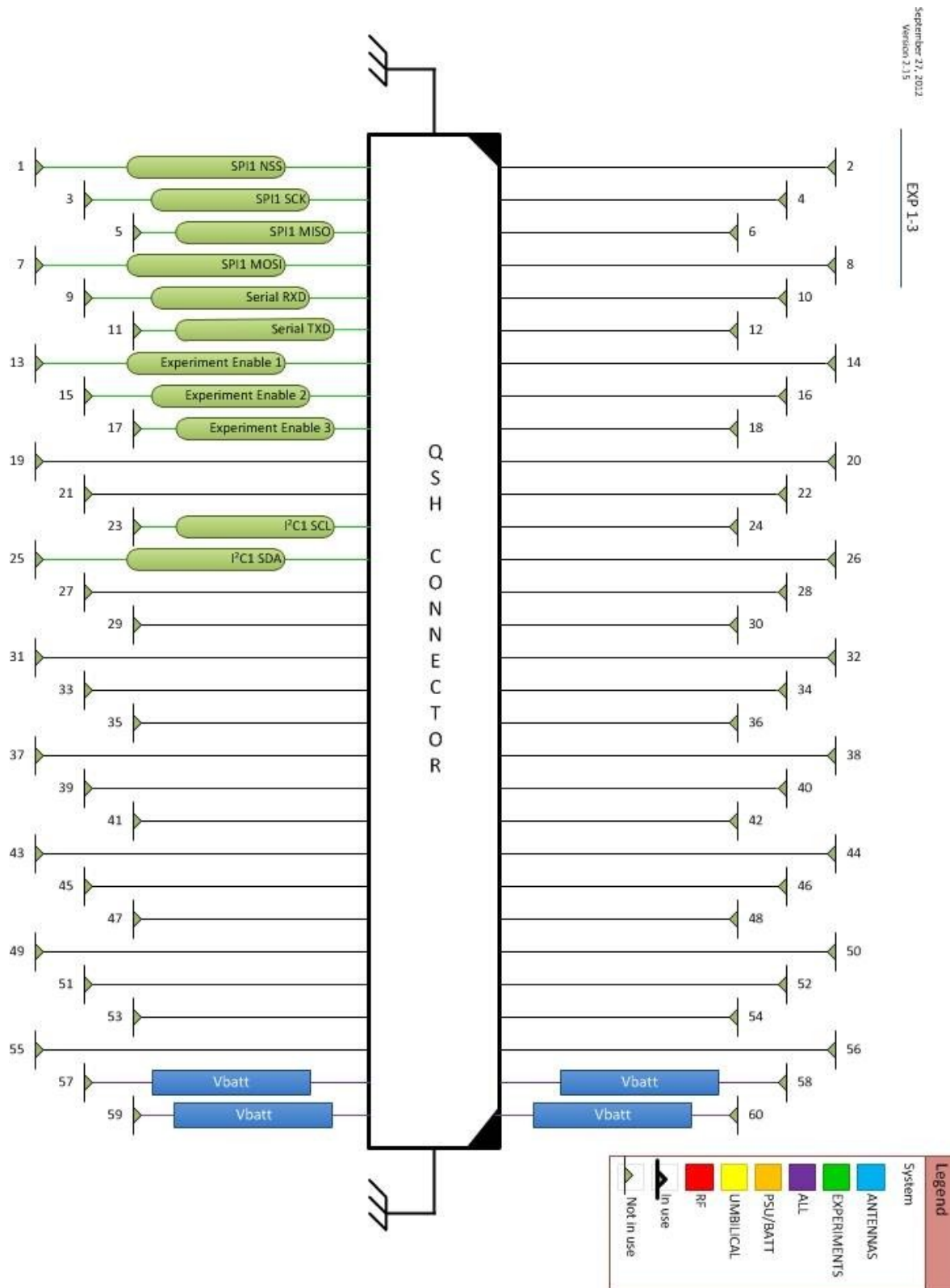


Figure 14: Experiment Payload 1-3 Systems Bus Connection Pin Assignments

8.6 Experiment Payload 4 System PCB Bus Connections

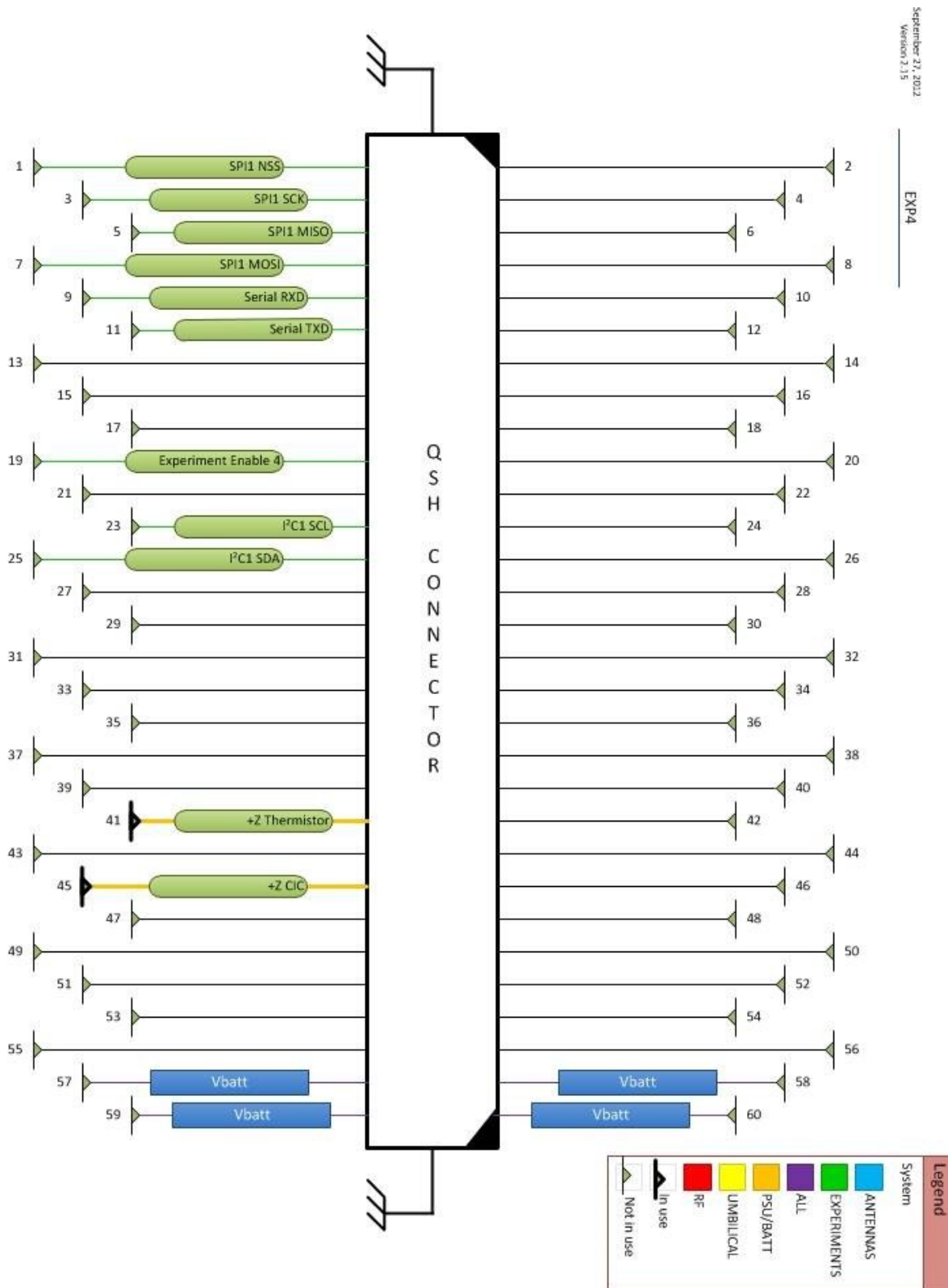


Figure 15: Experiment Payload 4 System Bus Connection Pin Assignments

8.7 Experiment Payload 4 System PCB External Connections

8.7.1 Three connections using Samtec FSI-105-06-L-S-AD connector

8.7.1.1 1 contact +Z Solar Panel Thermistor

8.7.1.2 1 contact +Z Solar Panel CIC +

8.7.1.3 1 contact common or - for above two connections

Table 10: +Z PCB face FSI-105-06-L-S-AD connector mates to pads on +Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	+Z Thermistor	Analog	N/A	N/A	N/A	PSU	41
2	N/C						
3	+Z Solar Panel Common						Ground Plane
4	N/C						
5	+Z CIC (+)	Analog	nominal	N/A	N/A	PSU	45

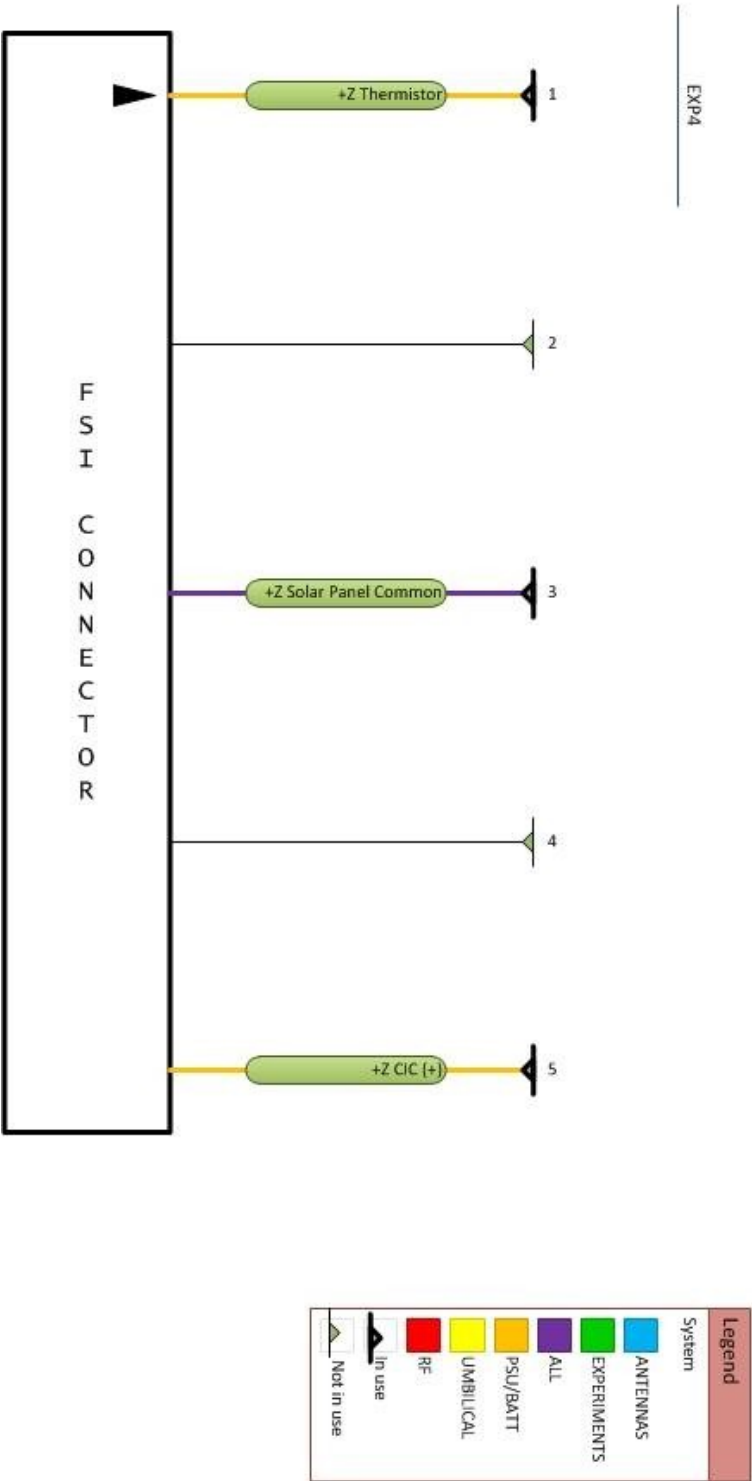
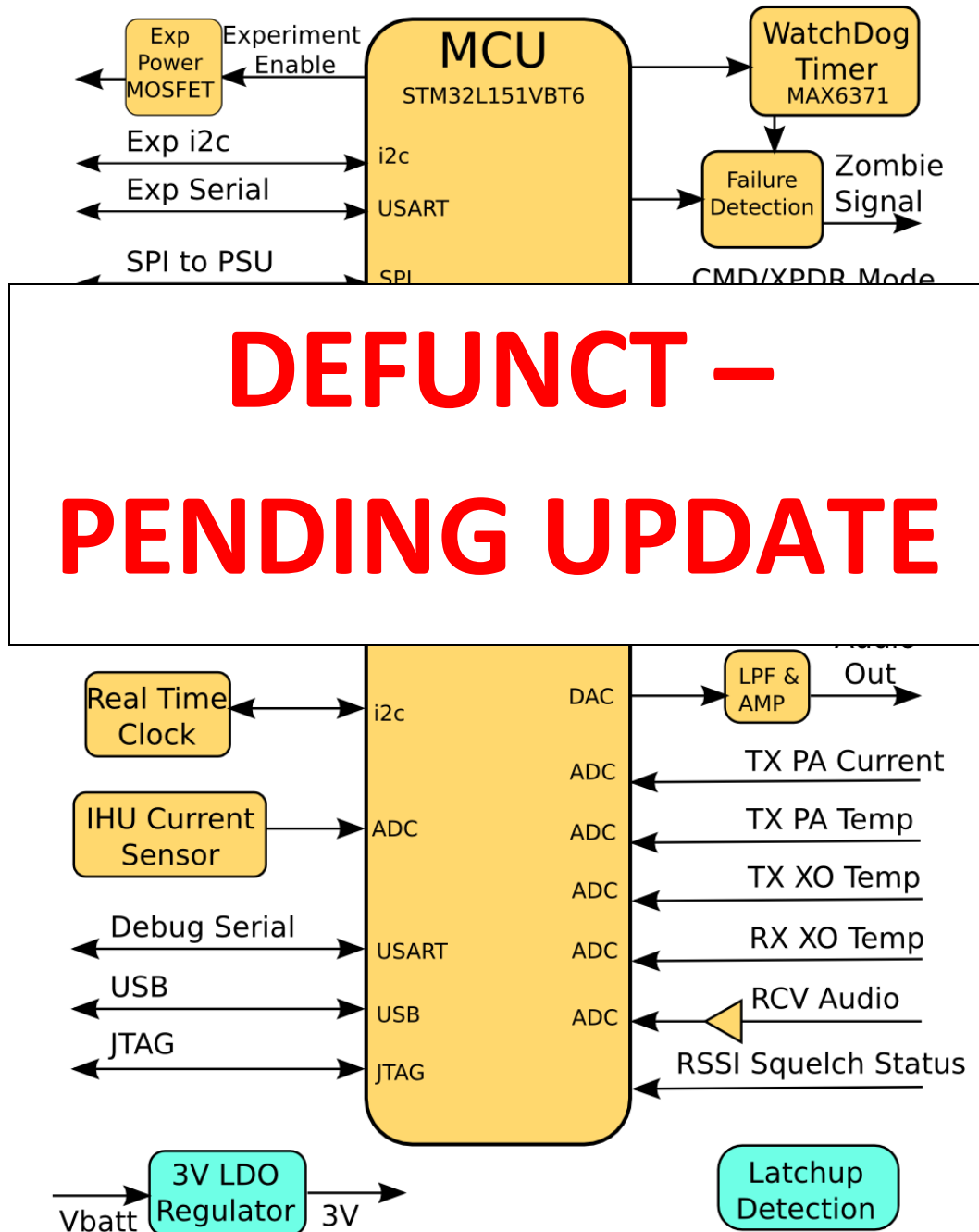


Figure 16: Experiment Payload 4 System FSI-105-06-L-S-AD
Connection Pin Assignments

9 System Block Diagrams Reference

9.1 IHU System

IHU Block Diagram Rev 2011-12-04

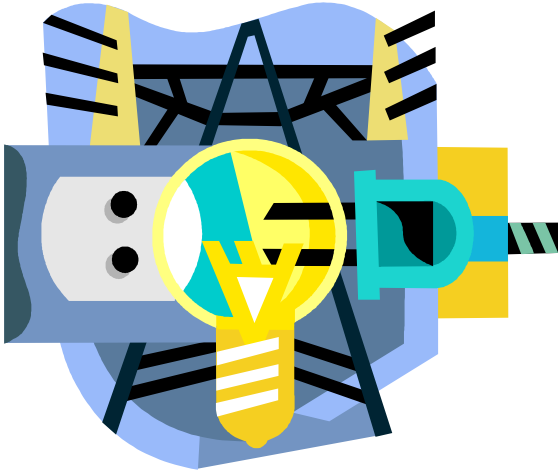




22 JUL 2012
V1R15

Baseband Audio
Interconnections
Indicated by Double
Stroke Line

9.3 PSU System (TBR)



10 System Interconnection References

10.1 Bus Connectors

- 10.1.1 Samtec QTH-030-02-L-D-A and QSH-030-01-L-D-A connectors
- 10.1.2 QTH connector shall be mounted on the +Z surface of each circuit board except the Receive Antenna PCB / GPS Payload circuit board
- 10.1.3 QSH connector shall be mounted on the -Z surface of each circuit board

10.2 Bus Connector Documentation

- 10.2.1 [Samtec QSH](#)
- 10.2.2 [Samtec QTH](#)
- 10.2.3 [Samtec QxH High Speed Characterization Report](#)
- 10.2.4 [Samtec QxH Single Ended Channel Properties](#)

10.3 External Connectors

- 10.3.1 Samtec MEC1-105-02-L-D-NP-A connector mounted on +X, -X, +Y, -Y Solar Panels
- 10.3.2 Samtec FSI-105-06-L-S-AD connector mounted on -Z face of RF Transmitter System PCB and +Z face of Experiment Payload 4 System PCB

10.4 External Connector Documentation

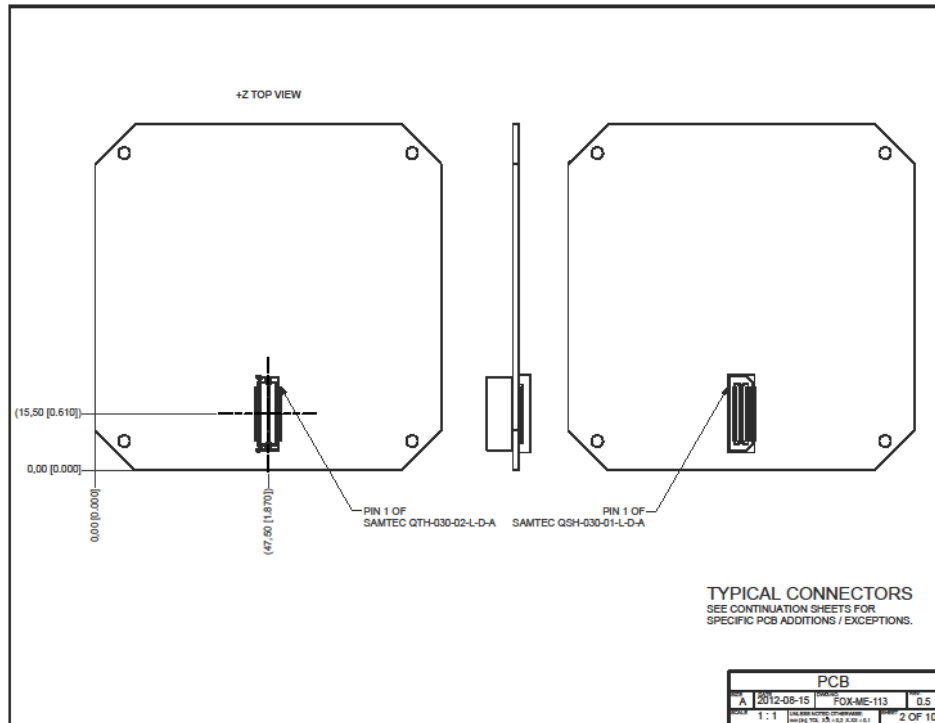
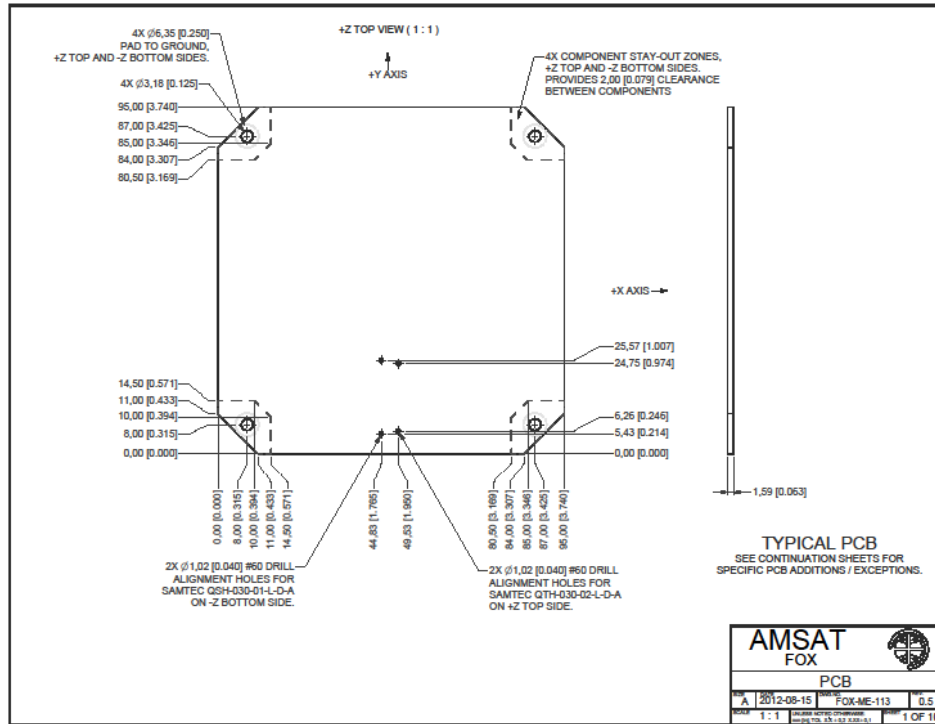
- 10.4.1 [Samtec MEC1](#)
- 10.4.2 [Samtec MEC1 Qualification Testing](#)
- 10.4.3 [Samtec FSI](#)

10.5 PCB Connector Layout Documentation

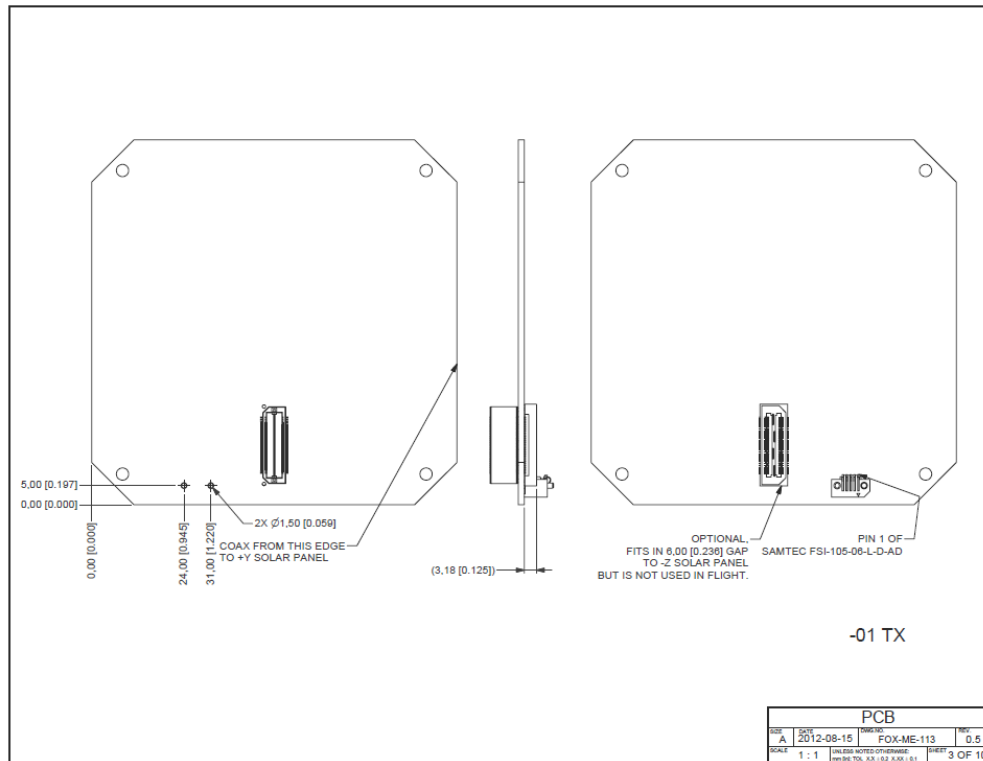
- 10.5.1 [FOX-ME-113_PCB.pdf](#)

10.6 Systems PCB Connector Layout

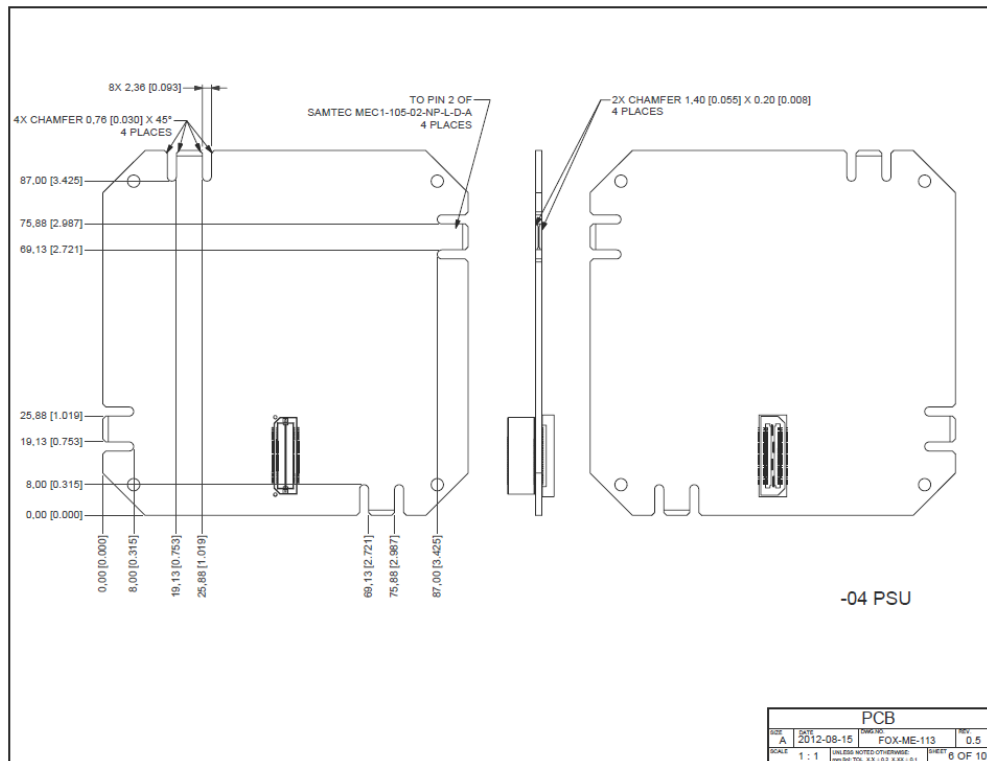
10.6.1 Common to All Systems



10.6.2 RF Transmitter System



10.6.3 PSU System



Technical drawing of PCB Experiment #4, showing top, side, and bottom views with dimensions and component labels.

Top View (Left): Shows the top of the PCB. Dimensions include 71.00 [2.795] and 64.00 [2.520]. A component is labeled "DO NOT POPULATE SAMTEC QTH-030-02-L-D-A EXCEEDS 8.00 [0.236] GAP TO +2 SOLAR PANEL". Another component is labeled "PIN 1 OF SAMTEC FSI-105-06-L-S-AD".

Side View (Middle): Shows the side profile of the PCB, indicating a thickness of 0.00 [0.000].

Bottom View (Right): Shows the bottom of the PCB. Dimensions include 5.00 [0.197] and 0.00 [0.000]. A component is labeled "2X Ø1.50 [0.056]".

Notes:

- HOLES MAY BE ADDED AROUND PERIMETER OF PCB FOR BALLAST MASSES
- 10 EXPERIMENT #4

PCB Table:

PCB			
REV	DATE	DESCRIPTION	REV
A	2012-08-15	FOX-ME-113	0.1
SCALE 1 : 1		UNLESS NOTED OTHERWISE	SHEET 10 OF 0.1

Date: June 29, 2012

Version: 2.0

AMSAT *Fox-1*

Attitude Determination Experiment Payload System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project attitude determination experiment payload.

The *Fox-1* satellite is a 1 Unit CubeSat with a primary mission of providing amateur radio communications. In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie, through an AMSAT sponsored senior design project.

The goal of the experiment will be to measure the spin rate and direction, about the Z axis of the satellite, and any off Z-axis “wobble”.

1.1 Document History

DATE	VERSION	SUMMARY
November 9, 2011	1.0	From Draft F
December 4, 2011	1.01	Fix formatting
December 23, 2011	1.03	Update references to other documents
December 27, 2011	1.04	Update 2.1.13 for QTH/QSH connectors
February 12, 2011	1.10	Change bus to SPI and add power signal Removed references to multiple PCBs and conflicting component placement Adjust PCB stay out zone and other requirements per latest mechanical revisions
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the experiment payload at the system (i.e. "black box") level. It is intended to be used to by the hardware,

AMSAT *Fox-I*
Attitude Determination Experiment Payload System Requirements



software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity are *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-I*, Concept of Operations, Version 1.03, September 19, 2011
2. AMSAT *Fox-I*, System Requirements Specification, Version 1.1, April 29, 2012
3. AMSAT *Fox-I* IHU to Attitude Determination Experiment Interface Control Document, Version 2.0, June 29, 2012

2 General Requirements

2.1 Physical Requirements

- 2.1.1 The experiment payload shall be constructed on the satellite IHU system PCB.

2.2 Environmental Requirements

- 2.2.1 The experiment payload shall be designed for -40C to +70C operating temperature.

3 Functional Requirements

3.1 Experiment Data

- 3.1.1 The experiment payload shall measure the spin rate and direction about the Z axis of the satellite.
- 3.1.2 The experiment payload shall measure any deviation (*wobble*) of the Z axis of the satellite caused by the spin of the satellite.
- 3.1.3 The experiment payload data shall have an accuracy of 1 degree.
- 3.1.4 The experiment payload shall be able to resolve the rate of spin in the range of 0 to 50 degrees per second. The experiment payload shall be able to resolve the deviation of the Z axis (*wobble*) in the range of 0 to 50 degrees.

3.2 Satellite Interface

- 3.2.1 The experiment data shall be directly collected by the satellite IHU system.

3.3 Power

- 3.3.1 The experiment payload shall receive electrical power from the satellite battery and photovoltaic panels.
- 3.3.2 The electrical power voltage will be nominally DC 3.6 V.
- 3.3.3 The satellite IHU system will activate and deactivate the experiment payload as necessary.
- 3.3.4 The electrical power drawn by the experiment payload shall not exceed 200 mW.

AMSAT Fox-1
Attitude Determination Experiment Payload System Requirements



3.4 Experiment Data

- 3.4.1 The IHU system shall process the experiment data for telemetry transmission†.
- 3.4.2 The IHU system shall sample the experiment data at a rate sufficient to provide telemetry data at least every 15 seconds.
- 3.4.3 The experiment payload data shall include the following measured and calculated parameters:

Parameter Name	Description
SPIN RATE	Rate of spin of the satellite about the Z axis, in degrees per minute
SPIN DIRECTION	Direction of spin of the satellite about the Z axis (+X or -X)
DEVIATION	Deviation (<i>wobble</i>) of +Z axis caused by satellite spin
UP TIME	Total seconds since experiment payload power-up or reset

†Note that the telemetry data frame is specified in the AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document.

4 External Interface Documents

To fully specify the experiment payload technical requirements, the following documents must also be provided;

1. AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document

5 Summary

The Fox-1 satellite attitude determination experiment payload will provide data on the spin and wobble of the passive-magnetically stabilized satellite. This includes the first known measurements of the wobble about the Z axis of a magnetically stabilized AMSAT satellite.

Date: September 18, 2012

Version: Version 1.91

AMSAT *Fox-1*

IHU to RF System Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the RF System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
March 24, 2012	1.0	Initial version
March 24, 2012	1.1	Add 2 nd RX Audio Out section 3.4.1
March 26, 2012	1.2	Section 3.2 rename Zombie to IHU Control, rename Audio to Audio 1, Section 3.4 remove RX Audio 2, section 4 removed entirely
March 26, 2012	1.3	Many updates using input from teams
March 30, 2012	1.4	Update 3.4.1.1 to clarify that receive signal CTCSS is responsible for state
March 31, 2012	1.5	3.3.1.3 updated to read no less than 100 mS
April 24, 2012	1.6	Update impedances and voltages to match SDS
June 18, 2012	1.7	Update 3.3.1.5 per PDR change to SRS, remove RESET add IHU OFF and IHU ON commands, signal characteristic updates per PDR, 3.4.1.2 to indicate command station signal strength
September 13, 2012	1.8	Remove IHU CONTROL signal, match signal characteristics to system design specification
September 16, 2012	1.9	Changes to 3.3.1.1 and Table 4 per Tony
September 18, 2012	1.91	Removed Command Table (section 3.3) and re-stated section 3.3 requirements accordingly

1.2 Document Scope

The purpose of this document is to specify the signal types, levels, and direction for connections between the IHU and the RF System as described in the AMSAT *Fox-I* System Requirements Specification.

1.3 References

1. AMSAT *Fox-I* System Requirements Specification
2. AMSAT *Fox-I* System Design Specification
3. AMSAT *Fox-I* IHU Software Architecture Specification

2 General Requirements

2.1 Telemetry

- 2.1.1 RF System Telemetry values shall be conveyed as analog voltage levels sent from the RF System to the IHU System.
- 2.1.2 The IHU System shall convert the analog signals to digital representations.
- 2.1.3 Audio signals for the purpose of conveying telemetry via sub-audible audio frequencies shall be sent from the IHU System to the RF System.

2.2 RF System Control

- 2.2.1 Control of the RF System shall be accomplished by means of digital signals sent from the IHU System to the RF System.

2.3 Satellite System Command

- 2.3.1 Command data for the purpose of controlling the satellite shall be processed by the RF System and sent to the IHU System.
- 2.3.2 Command data shall be conveyed to the IHU via digital signals.

2.4 Operational Components

- 2.4.1 Demodulated baseband audio signals shall be passed from the RF System to the IHU System for processing.
- 2.4.2 Baseband audio signals shall be passed from the IHU System to the RF System for transmission.
- 2.4.3 Operational Status signals shall be conveyed as digital signals sent from the RF System to the IHU System.

2.5 Signal Transmission

- 2.5.1 Signals shall use the pin assignments shown in the Fox-1 System Design Specification document.
- 2.5.2 Signal connections shall comply with the impedance and signal type shown in the parameters for each type of signaling.

2.6 Signal Type Definitions and Levels

- 2.6.1 **Analog:** 0.1 – 3.5 VDC analog voltage.
- 2.6.2 **Digital:** 3.0 VDC logic levels.
 - 2.6.2.1 Digital signals High State shall be ≥ 2.4 V.

2.6.2.2 Digital signals Low State shall be ≤ 0.4 V.

3 Signal Connection Requirements

3.1 Telemetry

3.1.1 The RF System shall provide raw telemetry values from the RF System components as shown in Table 1.

Table 1

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 k Ω	IHU	
4	TX PA Temperature	Analog	100-2000 mV	TX	30 - 60 k Ω	IHU	Analog Devices TMP36F
6	TX Osc Temperature	Analog	100-2000 mV	TX	30 - 60 k Ω	IHU	Analog Devices TMP36F
8	RX Osc Temperature	Analog	100-2000 mV	RX	30 - 60 k Ω	IHU	Analog Devices TMP36F

3.1.1.1 The values shall be updated at a rate to provide new samples at least every 15 seconds.

3.2 RF System Control

3.2.1 The IHU System shall provide control and audio signals to the RF System as shown in Table 2.

Table 2

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
12	IHU Audio 1 Out	Analog	2 V p-p audio	IHU	600 Ω , Unbalanced	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
26	COMMAND Mode	Digital		IHU		TX	HIGH = Command Mode
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT

3.2.1.1 COMMAND Mode signal when High shall inhibit received RF audio retransmission (COMMAND MODE).

3.2.1.2 IHU PTT signal when High shall key the RF transmitter on.

3.3 Satellite System Command

3.3.1 The RF System shall provide ground station command signals to the IHU System as shown in Table 3.

Table 3

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
16	RX Command Data 8	Digital		RX		IHU	
18	RX Command Data 9	Digital		RX		IHU	
20	RX Command Data 10	Digital		RX		IHU	
22	RX Command Data 11	Digital		RX		TX	
24	RX Command Strobe	Digital		RX	30 - 60 k Ω	IHU	

- 3.3.1.1 RX Command data shall be read on the rising edge of the RX Command Strobe signal.
- 3.3.1.2 Upon an RX Command Strobe rising transition the IHU System shall read the signal values RX Command Data 8, RX Command Data 9, and RX Command Data 10.
- 3.3.1.3 The duration of an RX Command Strobe signal High state shall be no less than 500 mS.
- 3.3.1.4 RX Command Data 11 shall be the most significant bit, RX Command Data 8 shall be the least significant bit.

Note that the control interface will be specified in a separate document.

3.4 Operational Components

- 3.4.1 The RF System shall provide operational and audio signals to the IHU System as shown in Table 4.

Table 4

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
30	RX PTT	Digital		TX	30 - 60 k Ω	IHU	HIGH = HANG TIMER ACTIVE
32	RX CD	Digital		RX	30 - 60 k Ω	IHU	
34	RX Audio 1	Analog	2 V p-p audio	RX	600 Ω , Unbalanced	IHU	10 Hz - 7 kHz bandwidth

- 3.4.1.1 TX Active signal when High shall indicate that the transponder uplink signal CTCSS hang timer is activating the RF transmitter.
- 3.4.1.2 RX CD signal when High shall indicate that the RF receiver detects a signal on the uplink.

Date: August 7, 2012

Version: Version 1.03

AMSAT *Fox-1*

IHU to PSU Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Power Supply (PSU) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	Initial version
February 21, 2012	1.01	Clarify I ² C address
March 7, 2012	1.02	2.3.1 updated Vdd to 3.0V
August 7, 2012	1.03	Remove BATT1 data fields and adjust message accordingly

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the PSU as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The PSU shall be the I²C Slave.

2.1.2.1 The IHU shall request the PSU to send.

2.1.2.2 The PSU shall send a single telemetry data message.

2.1.3 Each telemetry data message sent by the PSU shall be preceded by a header containing the message version and the software version of the PSU.

2.1.4 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each telemetry data message shall contain a header block, a data block, and a CRC block.

2.2.2 The PSU shall sample data at a rate sufficient to provide telemetry data to the IHU at least every 15 seconds.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The PSU I²C 7 bit address shall be 0x10.

3 Message Content Requirements

3.1 Message Header Block

3.1.1 The message header block shall be constructed as shown in table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
Message Version	2	Unsigned integer	Variable	Message ICD version
Software Build	2	Unsigned integer	Variable	Software Build version

3.1.1.1 The Message Version shall be an integer representing the IHU to PSU ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.1.1.2 The Software Build shall be an integer representing the software build version number of the PSU system, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.2 Message Data Block

3.2.1 The message data block shall be constructed as shown in Table 2.

Table 2

Field	Size (Bytes)	Type	Value	Description
DATA	28	Unsigned integers	Variable	Message data

3.2.2 The message data block shall contain the DATA fields as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Value	Description
TOTAL I	2	Unsigned integer	Variable	Total system DC current raw value
+X PANEL V	2	Unsigned integer	Variable	+X solar panel voltage raw value
-X PANEL V	2	Unsigned integer	Variable	-X solar panel voltage raw value
+Y PANEL V	2	Unsigned integer	Variable	+Y solar panel voltage raw value
-Y PANEL V	2	Unsigned integer	Variable	-Y solar panel voltage raw value
+Z PANEL V	2	Unsigned integer	Variable	+Z solar panel voltage raw value
-Z PANEL V	2	Unsigned integer	Variable	-Z solar panel voltage raw value
+X PANEL T	2	Unsigned integer	Variable	+X solar panel temperature raw value
-X PANEL T	2	Unsigned integer	Variable	-X solar panel temperature raw value
+Y PANEL T	2	Unsigned integer	Variable	+Y solar panel temperature raw value
-Y PANEL T	2	Unsigned integer	Variable	-Y solar panel temperature raw value
+Z PANEL T	2	Unsigned integer	Variable	+Z solar panel temperature raw value
- Z PANEL T	2	Unsigned integer	Variable	-Z solar panel temperature raw value
SPIN	2	Unsigned integer	Variable	Calculated spin rate

3.3 CRC Block

3.3.1 The CRC block shall be constructed as shown in Table 4.

Table 4

Field	Size (Bytes)	Type	Value	Description
CRC	1	CRC	Variable	CRC-8-CCITT

3.3.1.1 The CRC shall be CRC-18-CCITT (0x07).

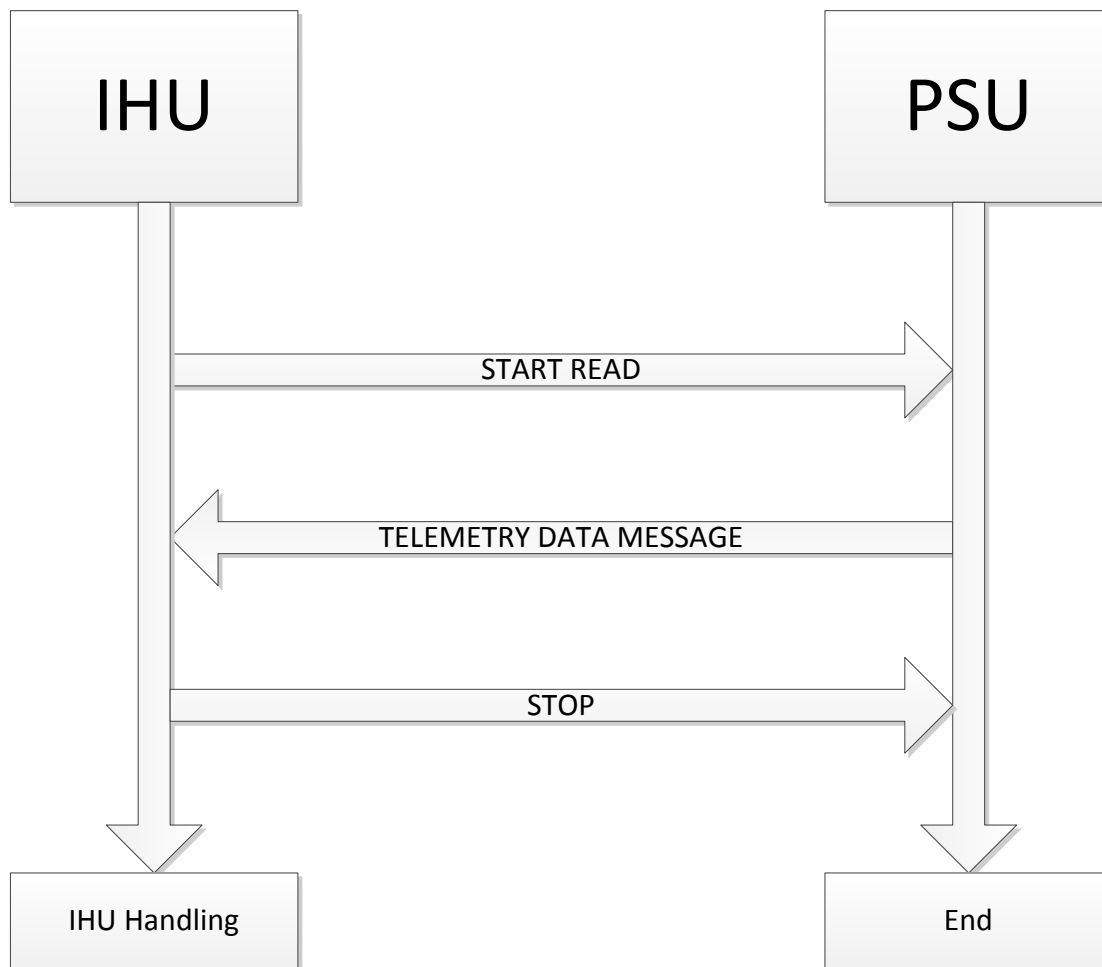
4 Message Integrity

4.1.1 If the CRC fails, the message shall be considered invalid.

4.1.2 If the Message Version does not match the message version in use for the construction of messages on the IHU system, the message shall be considered invalid.

5 Message Flow Diagrams

5.1 READ



Date: August 7, 2012
Version: Version 1.00

AMSAT *Fox-1*

IHU to Battery Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Battery (BATT1) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
August 7, 2012	1.00	Initial version

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the BATT1 as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The BATT1 shall be the I²C Slave.

2.1.2.1 The IHU shall request the BATT1 to send.

2.1.2.2 The BATT1 shall send a single telemetry data message.

2.1.3 Each telemetry data message sent by the BATT1 shall be preceded by a header containing the message version and the software version of the BATT1.

2.1.4 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each telemetry data message shall contain a header block, a data block, and a CRC block.

2.2.2 The BATT1 shall sample data at a rate sufficient to provide telemetry data to the IHU at least every 15 seconds.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The BATT1 I²C 7 bit address shall be 0x1B.

3 Message Content Requirements

3.1 Message Header Block

3.1.1 The message header block shall be constructed as shown in table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
Message Version	2	Unsigned integer	Variable	Message ICD version
Software Build	2	Unsigned integer	Variable	Software Build version

3.1.1.1 The Message Version shall be an integer representing the IHU to BATT1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.1.1.2 The Software Build shall be an integer representing the software build version number of the BATT1 system, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.2 Message Data Block

3.2.1 The message data block shall be constructed as shown in Table 2.

Table 2

Field	Size (Bytes)	Type	Value	Description
DATA	14	Unsigned integers	Variable	Message data

3.2.2 The message data block shall contain the DATA fields as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Value	Description
CELL 1 V	2	Unsigned integer	Variable	Battery cell 1 voltage raw value
CELL 2 V	2	Unsigned integer	Variable	Battery cell 2 voltage raw value
CELL 3 V	2	Unsigned integer	Variable	Battery cell 3 voltage raw value
CELL 4 V	2	Unsigned integer	Variable	Battery cell 4 voltage raw value
CELL 5 V	2	Unsigned integer	Variable	Battery cell 5 voltage raw value
CELL 6 V	2	Unsigned integer	Variable	Battery cell 6 voltage raw value
CELL T	2	Unsigned integer	Variable	Battery temperature raw value

3.3 CRC Block

3.3.1 The CRC block shall be constructed as shown in Table 4.

Table 4

Field	Size (Bytes)	Type	Value	Description
CRC	1	CRC	Variable	CRC-8-CCITT

3.3.1.1 The CRC shall be CRC-18-CCITT (0x07).

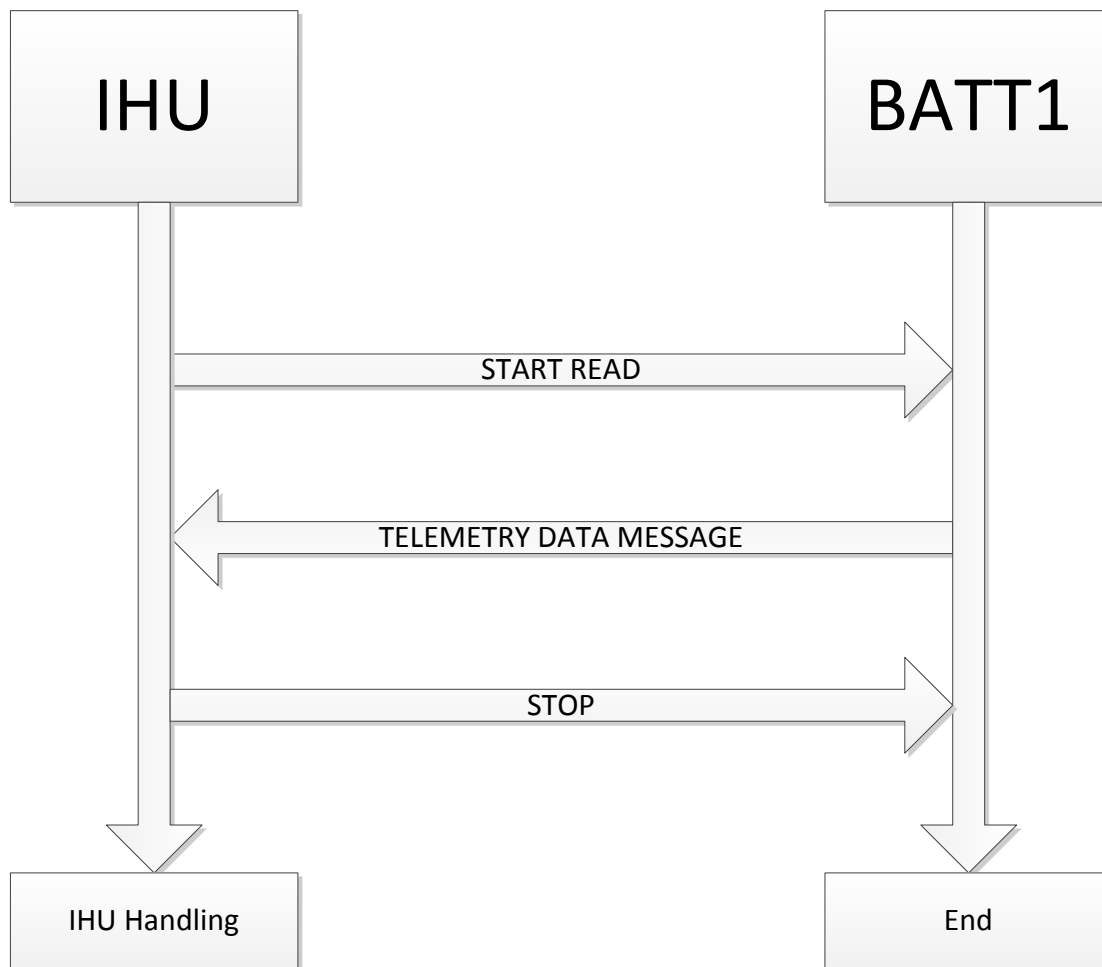
4 Message Integrity

4.1.1 If the CRC fails, the message shall be considered invalid.

4.1.2 If the Message Version does not match the message version in use for the construction of messages on the IHU system, the message shall be considered invalid.

5 Message Flow Diagrams

5.1 READ



Date: June 29, 2012

Version: Version 2.0

AMSAT *Fox-1*

IHU to Attitude Determination Experiment Interface Control Document

1 Introduction

This document specifies the message interface and the power activation interface between the Internal Housekeeping Unit (IHU) system and the Experiment Payload, as required per the AMSAT *Fox-1* Attitude Determination Experiment Payload System Requirements Specification document.

The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
February 12, 2012	1.0	From Draft and now SPI
February 15, 2012	1.01	Add SPI Bus Hardware Interface Requirements Change to DATA block types and values
February 20, 2012	1.02	Add SPI framing and CRC polynomial
February 20, 2012	1.03	Requirements Tracking Changes
February 21, 2012	1.04	Deviation corrected from 90 to 50 per Experiment System Requirement 3.1.5
February 26, 2012	1.05	Corrected description of SPIN RATE field in Table 6 to read seconds instead of minutes
March 7, 2012	1.06	Change 6.1.1.1 high state signal to $\geq 2.4V$
April 5, 2012	1.07	Add new DATA field MEMS GYRO STATUS
April 9, 2012	1.08	Added requirement 2.2.4
April 11, 2012	1.1	Add bits to MEMS GYRO STATUS
April 24, 2012	1.11	Set logic level Low as $\leq 0.2V$ in 6.1.1.2
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the data format for the communications between the Attitude Determination Experiment and the IHU system, as described in the

AMSAT *Fox-I*
IHU to Attitude Determination Experiment ICD



AMSAT *Fox-I* Attitude Determination Experiment Payload System Requirements Specification.

1.3 References

1. AMSAT *Fox-I* System Requirements Specification, Version 1.1, April 29, 2012
2. AMSAT *Fox-I* Experiment Payload System Requirements Specification, Version 2.0, June 29, 2012
3. AMSAT *Fox-I* IHU Software Architecture Specification, Draft E, January 19, 2012

2 Telemetry Content Requirements

2.1 Telemetry Data Block

2.1.1 The telemetry data block shall contain the data fields as shown in Table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
SPIN RATE	2	Signed integer	Variable -50 to +50	Rate of spin of the satellite about the Z axis, in degrees per second. Negative indicates -X spin direction, positive indicates +X spin direction.
DEVIATION	2	Unsigned integer	Variable 0 to +50	Deviation (wobble) of Z axis in degrees.
UP TIME	2	Unsigned integer	Variable 0 to 65535	Total seconds since experiment payload power-up or reset

Date: January 19, 2012
Version: *draft E*

AMSAT *Fox-1*

IHU Software Architecture Specification

1 Introduction

This document specifies the software architecture design for the IHU of the AMSAT Fox-1 satellite.

1.1 Document History

DATE	VERSION	SUMMARY

1.2 Document Notes

Procedures are described in this document using a "C-like" *psuedocode* syntax. This is intended to be a high-level description of the procedures and not compilable code.

1.3 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.03, OCT 19, 2011
2. AMSAT *Fox-1*, System Requirements Specification, Version 1.03, OCT 23, 2011

2 Interfaces

This section specifies the signals and information elements that interface with the IHU software. This document provides the high-level semantics. An interface specification is expected to be produced for each of these that provides the detailed syntax, bit patterns, timing, levels etc. required to run the interfaces.

2.1 PSU Telemetry

These data elements come from the PSU via an I2C interface

Name	Number of parameters
Battery Cell Volts	6
Solar Panel Volts	6
Solar Panel Temperature	6
Battery Temperature	1
Avionics Current	1
Calculated Spin rate	1

2.2 IHU Telemetry

This is the telemetry information from the IHU card. It comes directly from the STM32 CPU itself.

Name	Type	Description
CPU Temp	A/D	STM32 temperature

2.3 RF Telemetry

These are the telemetry elements from the RF card. They are sensed via analog levels that are sent to the A/D converter channels on the CPU.

Name	Type	Description
PA Current	A/D	Tx Power Amplifier Current
PA Temp	A/D	Tx Power Amp Temperature
Rx Osc Temp	A/D	Rx Oscillator Temperature
Tx Osc Temp	A/D	Tx Oscillator Temperature

2.4 RF Downlink

These are the signals needed to operate the RF downlink. These are via GPIO leads and D/A channels.

Name	Type	Description
Tx Active	input	TRUE if 2-min CTCSS timer is active
RF Mode	output	Selects command or transponder mode
PTT	output	Turns on transmitter if not already on
Tx Narrow	D/A output	Low-bit-rate PCM samples to transmit
Tx Wide	D/A output	High-bit-rate PCM samples to transmit

2.5 RF Uplink

These are the signals from RF uplink. These are via GPIO leads and an A/D channel on the CPU. There is a hardware command decoder on the RF card and the decoded commands are sent digitally to the IHU card on the GPIO leads. The carrier detect (Rx CD) and received audio samples (Rx Audio) are not used on the initial Fox-1 mission.

Name	Type	Description
Rx CD	input	ON if Receiver has carrier - NOT USED
Rx Audio	A/D	Receiver audio samples - NOT USED
Rx CMD	input	Received command - 4-bits plus strobe

These are the received command values:

Bit Pattern	Command
1xxx	Tx Inhibit - done in HW
0000	Reset - done in HW
0001	Test
0010	Clear stored min/max telemetry values
0011	Transponder Mode
0100	Command Mode
0101	- Reserved -
0110	- Reserved -
0111	- Reserved -

2.6 Antenna System

These are GPIO leads. The antenna system has an active primary deployment mechanism and a passive backup mechanism. The primary is under control of the IHU software. The secondary mechanism uses UV radiation from the sun to deploy the antennas in the event of a failure of the primary mechanism. The backup mechanism may take some time (i.e. several weeks or months) to deploy the antennas should the primary fail. Therefore, the IHU software must always test the deployment status of the antenna system before activating the RF transmitter PTT. This is to prevent inadvertent damage to the RF transmitter if waiting for the secondary mechanism to deploy the antennas.

Since the antenna deployment mechanism has not yet been designed, information about the precise sequencing and operation of these signals is unknown at this time.

Name	Type	Description
Antenna Deployed	input	TRUE if Antennas are deployed
Deploy Antenna1	output	Turning ON deploys antenna 1
Deploy Antenna2	output	Turning ON deploys antenna 2

2.7 Zombie Detector

The Zombie detector is an external hardware device that checks the cpu for *sanity* and radiation-induced, CMOS latch-up conditions. The IHU software must pulse the Alive (GPIO) lead at least once per second. Failure to do this for any reason will cause the IHU to be power-cycled.

Name	Type	Description
Alive	output	Pulse resets Zombie timer

2.8 GPS Receiver

Power is controlled via a GPIO lead. Data is via a serial (UART) port: 4800 bps, 8 data bits, no parity bit, one stop bit. Uses National Marine Electronics Recommended Minimum Sentence C format. *The actual availability of the GPS receiver for the Fox-1 mission is currently unknown.*

Name	Type	Description
GPS Power	output	controls power to GPS receiver
GPS Data	UART	time, longitude, latitude and altitude

2.9 Experiment

This is the interface to the experiment subsystem. Power is controlled via a GPIO lead. Data is via an SPI port.

Name	Type	Description
Spin Rate	input	satellite spin rate and direction (signed)
Wobble	input	satellite maximum deviation angle from axis
EXP Power	output	controls power to experiment

2.10 Umbilical Port

The umbilical port is functionally a USB port. Unlike a standard USB port, the satellite batteries can be charged directly from the +5 lead on the USB connector. Since battery charging may require in excess of the standard USB current capability, a special power adapter will be used when charging the batteries so the port will appear as a self-powered device. To the USB host, the satellite will look like a COM port and will allow use of the standard host USB COM driver. The intention is that the satellite can be easily used with common terminal emulation programs such as PuTTY.

The Umbilical port is required for system test activities and during launch integration. It is also available for general use in software development. Additional commands can be added as needed. The only limitation is that there must not be any capability from this port to directly activate the transmitter PTT without first testing to insure that the antennas have been deployed as this could accidentally damage the satellite.

The following commands are the minimal set that is required.

2.10.1 Umbilical Port Display Functions

1. Display Telemetry Data
2. Display Experiment Data
3. Display Satellite Mode (command or transponder mode)
4. Display RF Status (Tx active)
5. Display Antenna Status (antennas deployed or not)
6. Display Up Time
7. Display Reset Count
8. Display Software Version
9. Display CPU available

2.10.2 Umbilical Port Control Functions

1. Load the CPU Program (FLASH) Memory
2. Clear Telemetry Min/Max data
3. Clear Reset Count
4. Clear non-volatile memory error count
5. Transponder Mode
6. Command Mode
7. Send Test Message
8. Reset CPU (let Zombie detector fire)
9. Force Antenna Deployment - must be a multi-step command (i.e. always ask "Are you sure?" !!!)

2.11 Non-volatile Memory

Certain satellite data is stored in non-volatile memory so that it will survive through a CPU reset. This data needs to be protected to reduce the bit errors due to space radiation. The protection must be at least double error detecting and single error correcting. The data stored is as follows:

1. Telemetry Min/Max values
2. Experiment Data
3. CPU Reset count
4. Running total of non-volatile memory error count (reported in telemetry)

2.12 Debug Port

This is a serial port available for SW development use. It is not needed or used for the mission. It is expected that a call to a debug "printf()" would direct the output string to the debug port. It is expected this port would use asynchronous ASCII 8 Data bits, no parity, 1 stop bit, 19.2 k bps. As an alternative, the Umbilical port could be enhanced to display software debug messages rather than use a dedicated serial port. This port could be used for a debugger such as GDB if desired.

3 IHU Start Up Sequence

This is the sequence of events after a CPU reset.

```
// Run Power On Self Test (POST)
// Max duration must be less than one second or pulse the Zombie detector
// Check the program FLASH and run some kind of CPU test - at the very
// least, test the CPU internal RAM.

calculate checksum on program FLASH;
compare with stored value;
if (no match) {
    halt and let Zombie detector fire;
}

check CPU;
if (CPU failed) {
    halt and let Zombie detector fire;
}

// POST passed. See if we need to deploy the antennas.
if ( (Umbilical Port is NOT active) AND (Antennas are NOT Deployed) ) {
    wait here 45 minutes while pulsing Zombie detector;
    Activate antenna deployment mechanism;
}

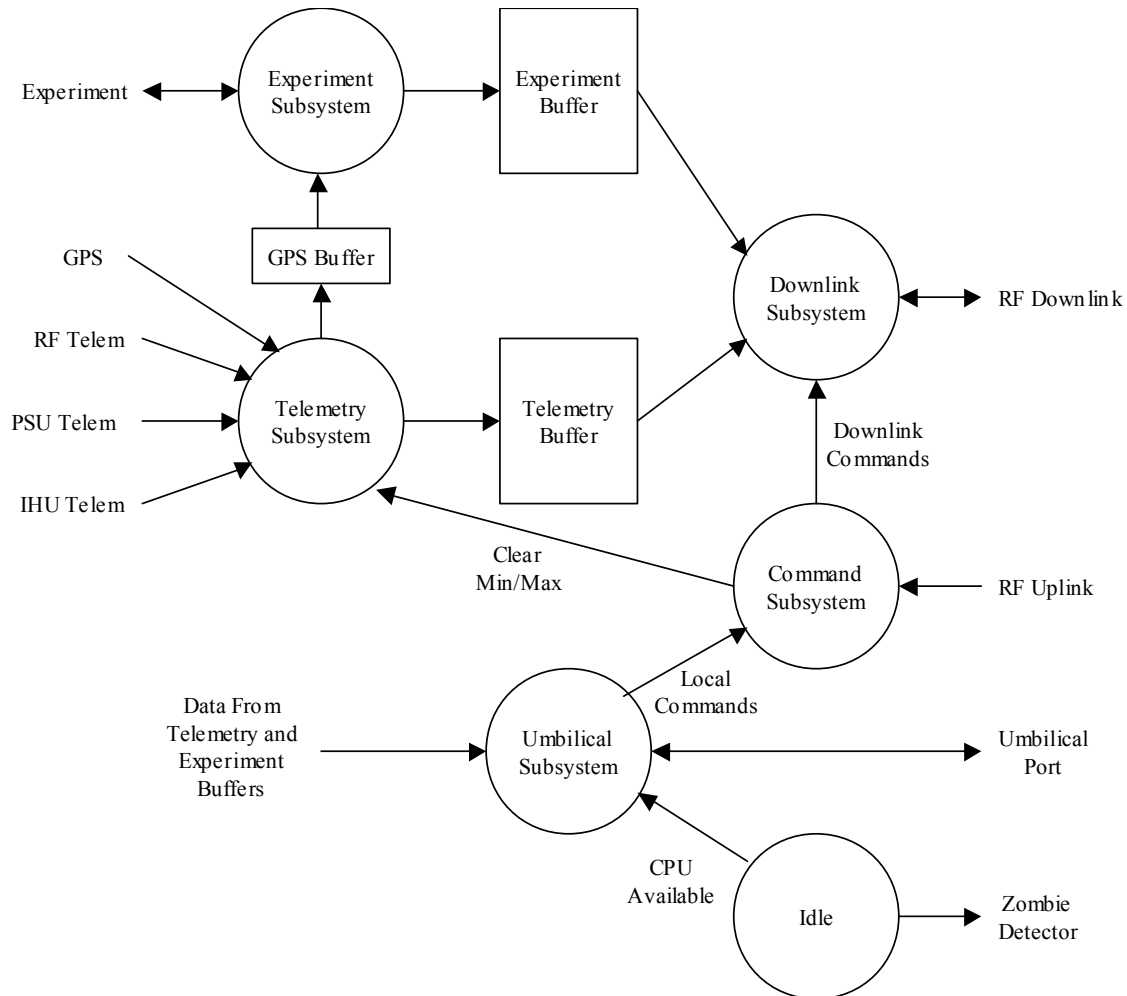
increment Reset Count in Non-Volatile Memory;

boot up system;

done;
```

4 Software Architecture

This shows the applications software subsystems and their interfaces after the start up sequence has been executed (i.e. after system boot up.) The required functionality of each subsystem is specified in this section.



4.1 Telemetry Subsystem

This module is responsible for collecting all of the telemetry and GPS information from all of the interfaces, doing the Min/Max telemetry processing and providing the data in the Telemetry Buffer.

4.1.1 Telemetry Buffer Data

```
Telemetry Data = {  
    CPU Up Time;  
    CPU Reset Count;  
    GPS Time;  
    GPS Location;  
    NV memory error count;  
    Current Telemetry Values { PSU, IHU, RF }  
    Min/Max Values;  
}
```

4.1.2 Telemetry Processing

Do this every 15 seconds;

Get all telemetry parameters from interfaces;

Get GPS data and save in GPS buffer;

// Do MinMax processing

Read Min/Max Data from non-volatile memory;

```
if (Clear Min/Max command was received) {  
    set Min/Max data to current telemetry values;
```

```
}
```

```
else {  
    update Min/Max data using current values;
```

```
}
```

Write new Min/Max data to non-volatile memory;

Get Up Time;

Get Reset Count;

Update data in Telemetry Buffer;

done;

4.2 Experiment Subsystem

The Experiment Subsystem is responsible for running the experiment, collecting the data, and updating the Experiment Buffer. The functionality of this subsystem depends directly on the experiment requirements and will likely be different for each the *Fox-1* type satellites.

The initial *Fox-1* satellite mission will fly the Penn State Attitude Determination Experiment. The required operation of this experiment is as follows. Once per day, the experiment is activated. Experiment data is sampled by the IHU every 3 minutes for one complete orbit. The orbit period will be approximately 100 minutes and a total of 34 data samples will be collected. If the experiment successfully runs to completion, the new experiment data is saved in non-volatile memory and the Experiment Buffer is updated with the latest values. In between experiment runs, the Experiment Buffer shall contain the data from the last successful experiment run or all 0's if it has not been run yet.

Note that the above description and following procedure is predicated on the assumption that the power system can provide enough power to run the experiment in both command and transponder mode. Based on current satellite bus and experiment power estimates, this is the case but should the situation change, this procedure may need to be modified.

4.2.1 Experiment Buffer Data

// This is the contents of each experiment data record

```
type Experiment Record = {  
    Spin Rate;  
    Wobble Angle;  
    GPS Location;  
};
```

// This is the data stored in the Experiment Buffer

```
Experiment Data = {  
    CPU Up Time;  
    CPU Reset Count;  
    GPS Time;  
    Experiment Record[34];  
}
```

4.2.2 Experiment Processing

```
Do this once at initialization {  
    Get saved Experiment Data from non-volatile memory;  
    if (data is valid) {  
        copy data to Experiment Buffer;  
    }  
    else {  
        clear Experiment Buffer;  
    }  
}  
  
Do this {  
    Wait 24 hours;  
    Power up experiment;  
    Get CPU Up Time;  
    Get CPU Reset Count;  
    Get GPS Time from GPS Buffer;  
    Save to a local data structure;      // Note: not in non-volatile memory!  
  
    Do this every 3 minutes for 34 times {  
        Get data from experiment;  
        Get GPS location from GPS Buffer;  
        Save in a local experiment record;  
    }  
  
    Power OFF experiment;  
    Copy saved local experiment data to non-volatile memory;  
    Update Experiment Buffer with saved local experiment data;  
}  
  
done;
```

4.3 Command Subsystem

This subsystem is responsible for handling demodulation, decoding and execution of commands sent from a ground control station via the RF uplink or from a local user via the Umbilical port. For the initial *Fox-1* mission, only the commands decoded in hardware on the RF card are needed so no additional software demodulation and decoding is necessary. This capability is reserved for use in future missions.

The Command Subsystem is responsible for controlling the satellite mode. Most commands are handled by just sending a message to the appropriate subsystem. However, if the satellite is in Command Mode, it must automatically switch to Transponder mode after 24 hours unless a new Command Mode command has been received.

4.3.1 Command Subsystem Processing

```
Do this continuously {  
    Monitor RF Uplink interface and Umbilical Subsystem for a new command;  
  
    if (Clear MinMax command is received) {  
        send clear telemetry message to Telemetry Subsystem;  
    }  
    else { // for. all other commands  
        send corresponding message to Downlink Subsystem;  
    }  
  
    if (command was Command Mode) {  
        Start or re-start the 24 hour timer;  
    }  
    if (received command was Transponder Mode) {  
        Stop the 24 hour timer;  
    }  
  
    if (24 hour timer expires) {  
        send transponder mode message to Downlink Subsystem;  
    }  
}  
  
done;
```

4.4 Downlink Subsystem

This subsystem is responsible for generating all of the downlink signals from the IHU. This includes telemetry and experiment data frames and CW messages.

To create a data frame, the Downlink Process will add framing information such as a satellite identifier, a data type field and frame number. The frame will have forward error correction and interleaving (FEC) added and the resulting bits will be used to generate the modulation waveform. The data format, framing, FEC and modulation details will be specified in the Telemetry Interface document.

The Downlink Subsystem has 2 modes of operation; transponder mode and command mode. These are controlled by messages from the Command Subsystem. The Downlink Subsystem starts up in transponder mode.

In transponder mode, the data frames are sent continuously as long as the RF transmitter is active. Data frames are sent at the low bit rate (~100 bps) to the RF card using the Tx Narrow (narrow band) D/A channel. Telemetry and experiment frames are multiplexed at a 5:1 ratio (i.e. 5 telemetry sent for each experiment frame.) If the RF transmitter is inactive for 5 minutes, a CW Beacon message is sent to the RF card using the Tx Wide (wide band) D/A channel. This continues every 5 minutes as long as the RF transmitter is otherwise inactive.

In command mode, the RF transmitter is power-cycled at a 50% duty cycle to save power. Approximately every 20 seconds, the transmitter is activated and the CW beacon message is transmitted followed by one telemetry frame and one experiment frame. Data frames are sent at the high bit rate (~10k bps.) The CW and data frames are sent to the RF card using the Tx Wide (wide band) D/A channel.

In either mode, if a TEST command is received from the uplink subsystem, the IHU will send the CW Test message and then revert to the prior mode operation.

As noted previously (see section 2.6 Antenna System,) it is essential that the IHU software refrain from activating the RF transmitter if the antennas have not been deployed. The IHU software will be needed for the launch integration activities while the satellite is inside the P-POD. Turning on the RF transmitter inside the P-POD could cause irreparable damage to the satellite. Similarly, should the primary antenna deployment mechanism fail for whatever reason, the satellite must not activate the RF transmitter until the backup (passive) mechanism has deployed the antennas.

4.4.1 Downlink Subsystem Processing

At initialization, enter Transponder Mode;

Continuously monitor interface to Uplink Subsystem for a command message;

```
In Transponder Mode {
    Put RF card in transponder mode;
    While (Tx Active) {
        Send 5 Telemetry frames at low data rate;
        Send 1 Experiment frame at low data rate;
    }
    While (NOT Tx Active) {
        start 5 minute timer;
        if (timer expires before Tx Active) {
            if (Antennas Deployed) {
                Put RF card in Command mode;
                Turn on PTT;
                Send CW beacon message;
                Send 1 Telemetry frame at high data rate;
                Send 1 Experiment frame at high data rate;
                Turn off PTT;
                Put RF card in Transponder mode;
            }
        }
    }
}

In Command Mode {
    Put RF card in command mode;
    Do this every 20 seconds {           // Set time to for 50% RF Tx duty cycle
        if (Antennas Deployed) {
            Turn on PTT;
            Send CW beacon message;
            Send 1 Telemetry frame at high data rate;
            Send 1 Experiment frame at high data rate;
            turn off PTT;
        }
    }
}
```


// Downlink Subsystem Processing continued

```
In either mode {  
    if (TEST command is received) {  
        save current downlink mode;  
        if (Antennas Deployed) {  
            Put RF card in Command mode;  
            Turn on PTT;  
            Send CW TEST message;  
            Turn off PTT;  
            Go back to previous downlink mode;  
        }  
    }  
}  
done;
```

4.5 Umbilical Subsystem

This implements a local user interface on the satellite. This is expected to be used for system testing and launch integration activities. The Umbilical Subsystem implements the commands that are specified in the Umbilical Port section of this document (section 2.1 Umbilical Port.) It is also available for software development use. This subsystem is not used in orbit.

4.6 Idle Subsystem

This subsystem handles the Zombie Detector and calculates the average available CPU. It is intended that this Subsystem will run only when no other Subsystem has anything to do. The Zombie detector is intended to detect transient CPU failures due to radiation events that cause a system lockup. The Zombie Detector must not be serviced via an interrupt as this could defeat the lockup protection.

5 System Considerations

5.1 Physical Device Drivers

This software is needed to access and control the IHU hardware.

1. I²C
2. SPI
3. UART
4. A/D converter channels
5. D/A converter channels
6. GPIO inputs
7. GPIO outputs

5.2 Logical Device Drivers

This is the software needed to support the IHU interfaces. They may make use of one or more underlying hardware drivers and provide the logical interfaces for the applications software.

1. PSU Telemetry
2. IHU Telemetry
3. RF Telemetry
4. RF Downlink
5. RF Uplink
6. Antenna System
7. Zombie Detector
8. GPS Receiver
9. Experiment
10. Umbilical Port
11. Non-volatile (EDAC) Memory
12. Debug Port (i.e. "printf()" facility)

5.3 Operating System

The IHU software will use the free version of the FreeRTOS operating system.

5.3.1 OS Task List and Priorities

5.3.2 Inter-Task Communications

5.4 Performance Requirements

The Downlink Tx Audio D/A converters have hard real-time requirements. DMA should be considered to offload the CPU for these interfaces.

5.5 CPU and Memory Constraints

Max CPU is 32 MHz.

Max RAM is 32K Bytes

Program FLASH is 128K bytes

5.6 Operational Constraints

System is intended to run on orbit but must also be able to run inside the P-Pod to support the launch integration activities. Inside the P-POD, the antennas **MUST NOT** be deployed automatically and the RF transmitter **MUST NOT** be activated!

5.7 Modularity and Maintainability

The experiment will likely be changed for each future *Fox-1* type satellite mission. The experiment processing software needs to be modularized so it is easy to change. New experiments may have different up link and downlink requirements.

6 External Interface Specifications

Although not part of this document, detailed specifications are needed for each external interface:

- PSU Interface
- RF System Interfaces
- Experiment Interface
- RF Downlink (Telemetry)
- Command Uplink
- Umbilical Port
- Antenna System
- Zombie Detector

7 Summary

This document specifies the Software Architecture for the AMSAT *Fox-1* satellite. This specification covers the initial mission flying the Penn State Attitude Experiment. Future missions may require changes to this specification in order to support the experiment.

Fox1 Antenna Details 2012-08-05

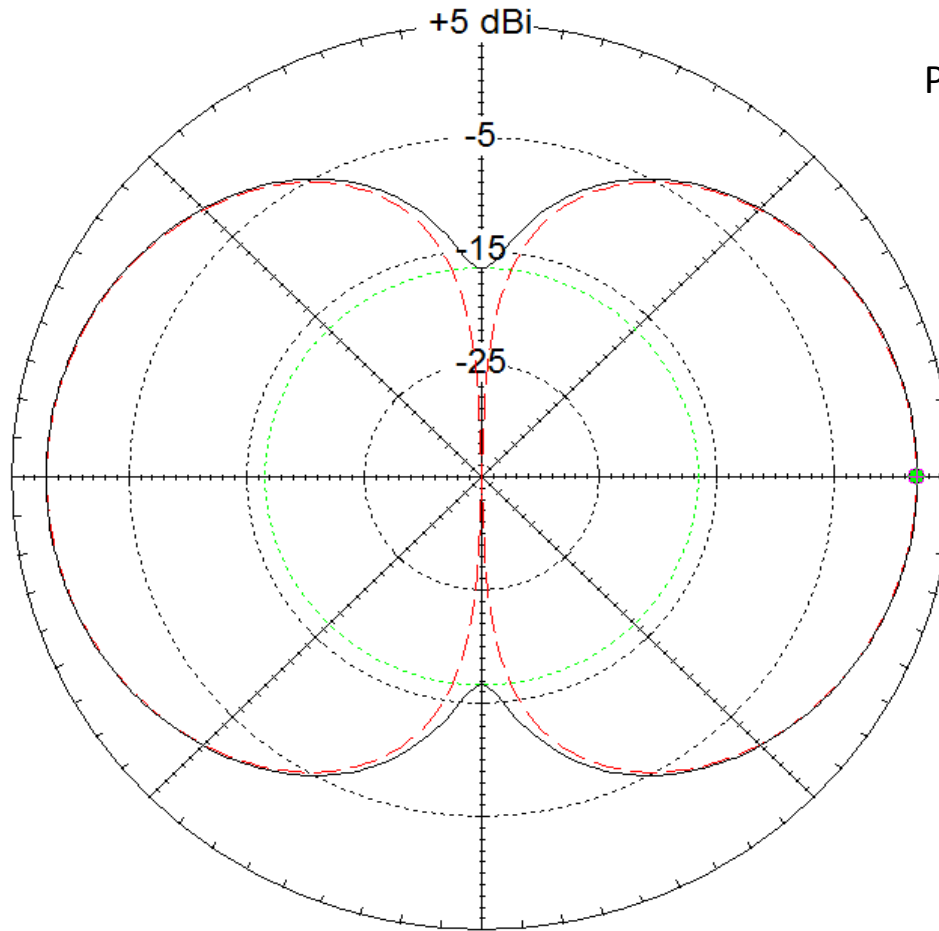
* Total Field

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +2.0 dBi



144 MHz

Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.06 dBi
Slice Max Gain 2.05 dBi @ Elev Angle = 0.0 deg.
Front/Side 18.62 dB
Beamwidth 83.3 deg.; -3dB @ 318.1, 41.4 deg.
Sidelobe Gain 2.05 dBi @ Elev Angle = 180.0 deg.
Front/Sidelobe 0.0 dB

2m antenna pattern in XZ plane
(theta cut at phi = 0 deg.)

Vertical Polarization (relative to satellite's XY
plane), horizontal, and total polarization.

Cursor Elev 0.0 deg.
Gain 2.05 dBi
0.0 dBmax
0.0 dBmax3D

Aug 5, 2012

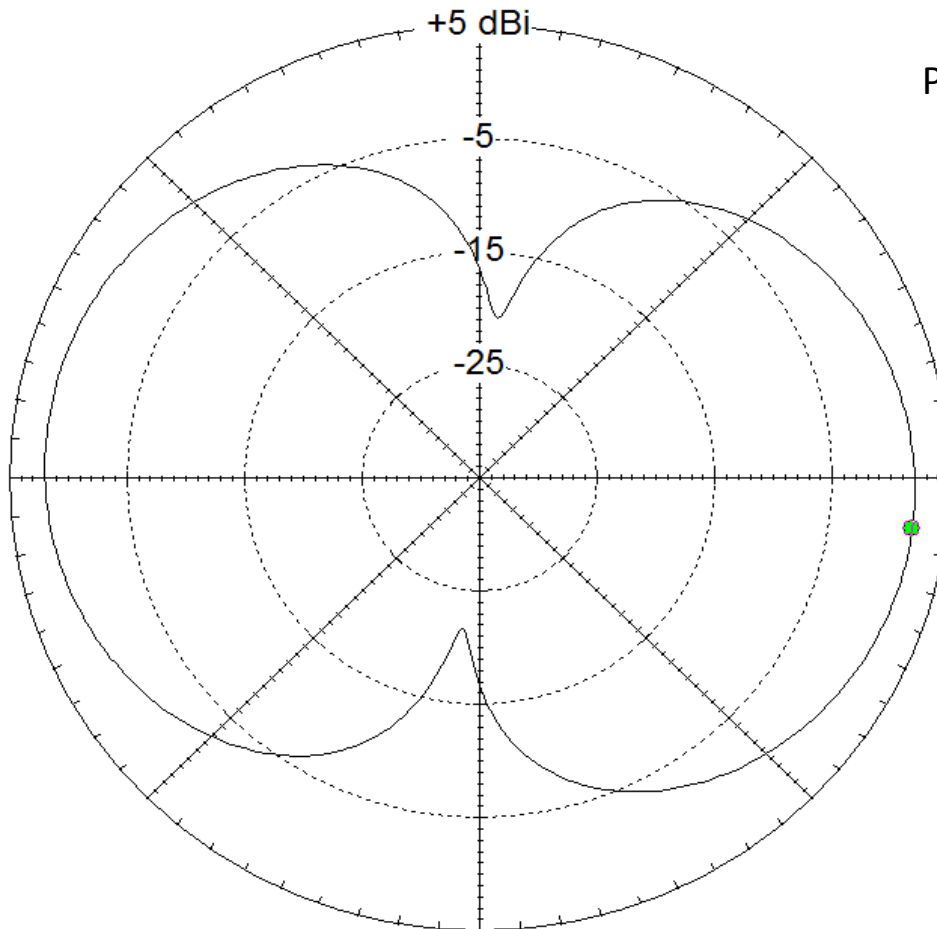
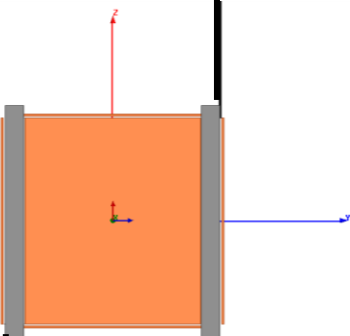
* Total Field

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +2.0 dBi



144 MHz

Elevation Plot
Azimuth Angle 90.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.06 dBi
Slice Max Gain 2.06 dBi @ Elev Angle = 353.0 deg.
Front/Back 0.04 dB
Beamwidth 82.8 deg.; -3dB @ 312.1, 34.9 deg.
Sidelobe Gain 2.02 dBi @ Elev Angle = 174.0 deg.
Front/Sidelobe 0.04 dB

2m antenna pattern in YZ plane
(theta cut at phi = 90 deg.)

Vertical Polarization (relative to satellite's XY
plane)

Cursor Elev -7.0 deg.
Gain 2.06 dBi
0.0 dBmax
0.0 dBmax3D

Aug 5, 2012

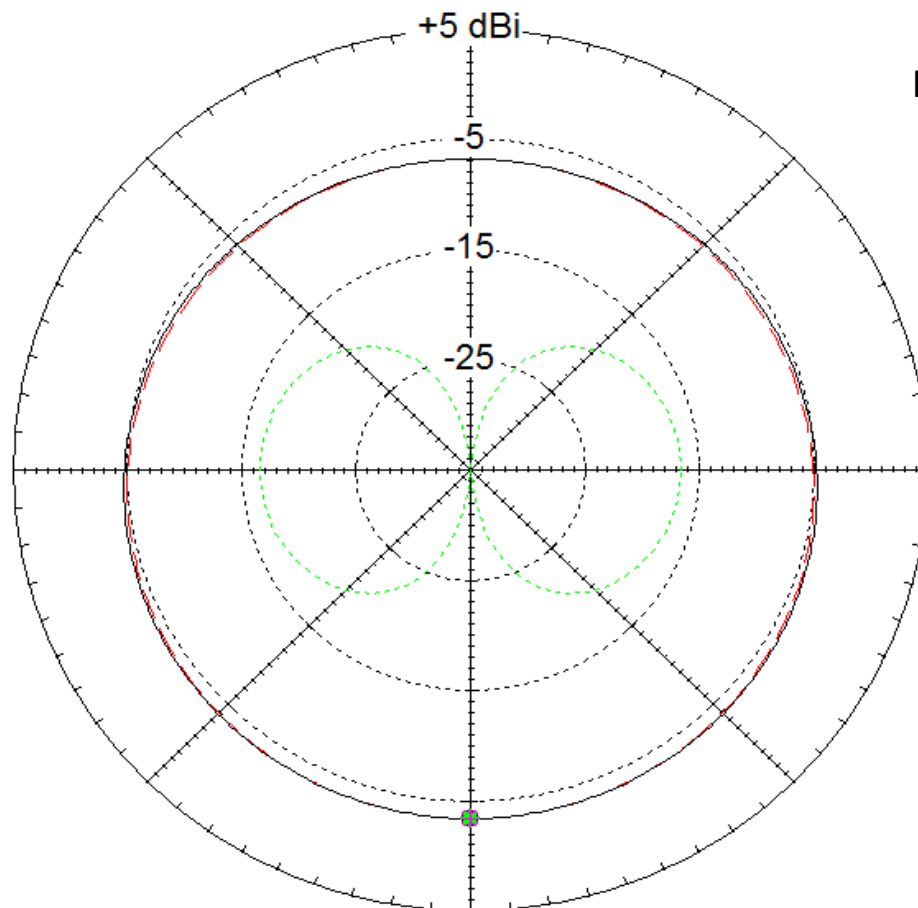
*** Total Field**

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = -3.4 dBi



Azimuth Plot
Elevation Angle 60.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.0 dBi
Slice Max Gain -3.38 dBi @ Az Angle = 270.0 deg.
Front/Back 3.43 dB
Beamwidth 292.0 deg.; -3dB @ 124.0, 56.0 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

2m antenna pattern
conical (phi) cut at theta = 30 deg. (60 deg.
Elevation); Vertical Polarization (relative to
satellite's XY plane)

144 MHz

Cursor Az 270.0 deg.
Gain -3.38 dBi
0.0 dBmax
-5.38 dBmax3D

Aug 5, 2012

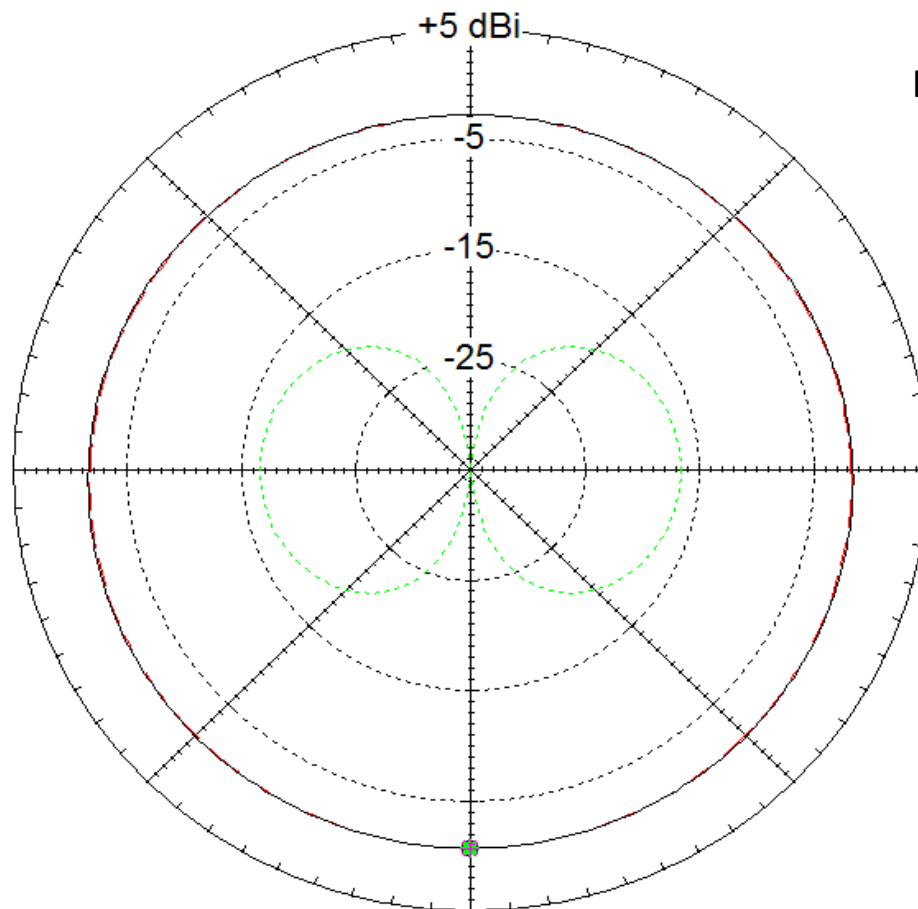
*** Total Field**

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = -0.7 dBi



Azimuth Plot
Elevation Angle 45.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.0 dBi
Slice Max Gain -0.69 dBi @ Az Angle = 270.0 deg.
Front/Back 2.11 dB
Beamwidth ?
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

2m antenna pattern
conical (phi) cut at theta = 45 deg. (45 deg.
Elevation); Vertical Polarization (relative to
satellite's XY plane)

144 MHz

Cursor Az 270.0 deg.
Gain -0.69 dBi
0.0 dBmax
-2.68 dBmax3D

Aug 5, 2012

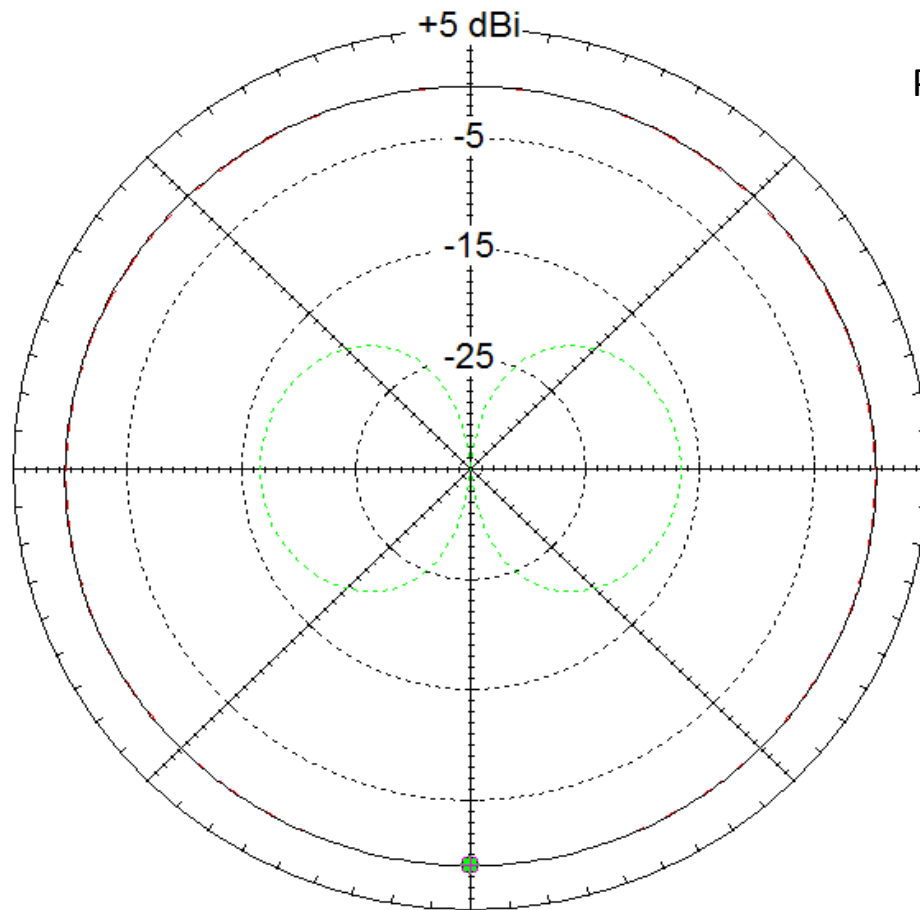
*** Total Field**

Horizontal Pol

Vertical Pol

EZNEC+

Peak gain = +1.0 dBi



Azimuth Plot
Elevation Angle 30.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.0 dBi
Slice Max Gain 0.98 dBi @ Az Angle = 270.0 deg.
Front/Back 1.29 dB
Beamwidth ?
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

2m antenna pattern
conical (phi) cut at theta = 60 deg. (30 deg.
Elevation); Vertical Polarization is relative to
satellite's XY plane.

144 MHz

Cursor Az 270.0 deg.
Gain 0.98 dBi
0.0 dBmax
-1.02 dBmax3D

Aug 5, 2012

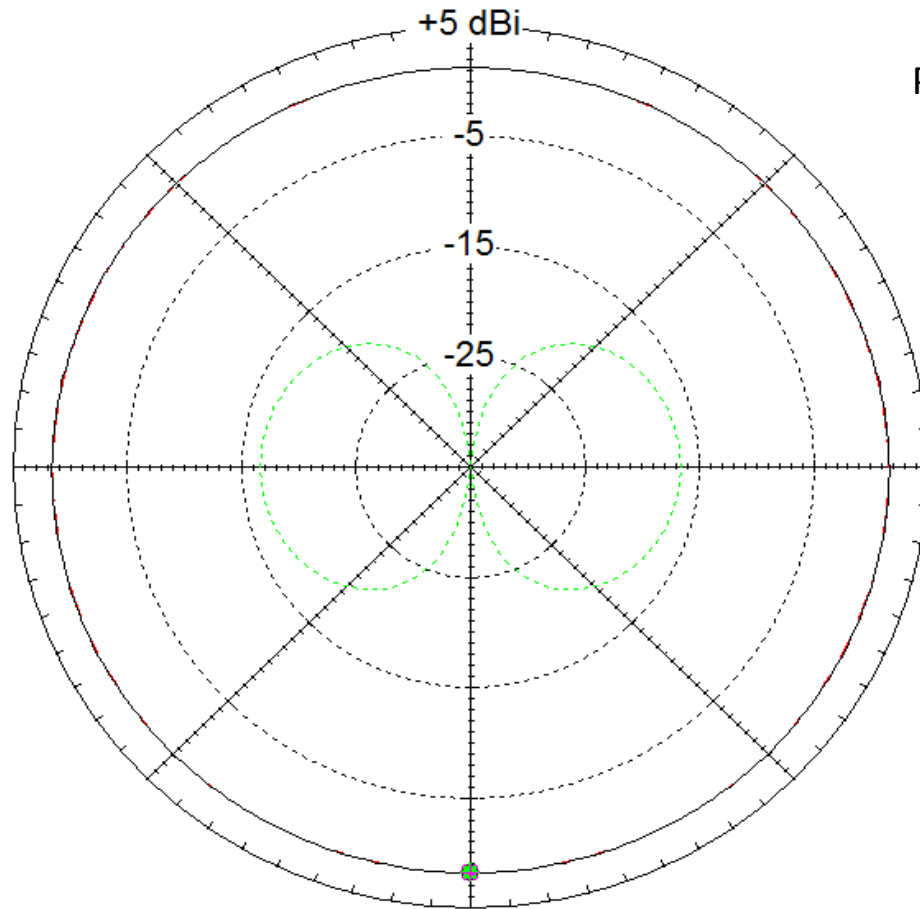
*** Total Field**

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +1.8 dBi



Azimuth Plot
Elevation Angle 15.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.0 dBi
Slice Max Gain 1.83 dBi @ Az Angle = 270.0 deg.
Front/Back 0.62 dB
Beamwidth ?
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

2m antenna pattern
conical (phi) cut at theta = 75 deg. (15 deg.
Elevation); Vertical Polarization is relative to
satellite's XY plane.

144 MHz

Cursor Az 270.0 deg.
Gain 1.83 dBi
0.0 dBmax
-0.17 dBmax3D

Aug 5, 2012

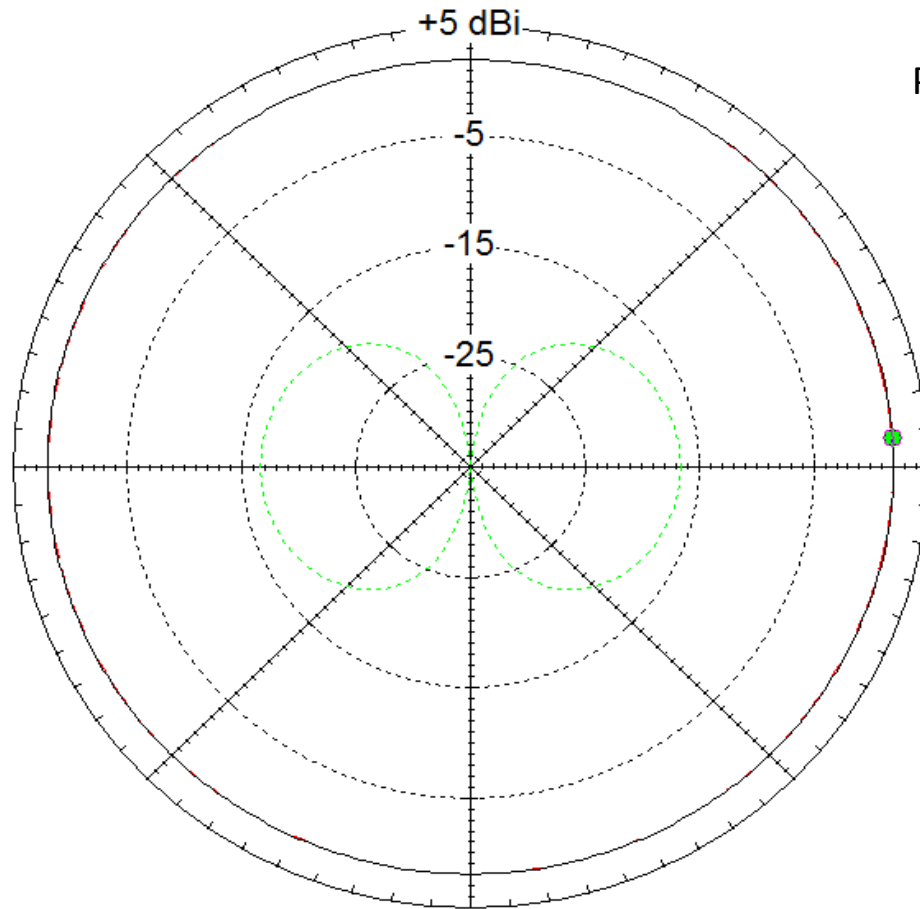
*** Total Field**

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +2.0 dBi



Azimuth Plot
Elevation Angle 0.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.0 dBi
Slice Max Gain 1.99 dBi @ Az Angle = 4.0 deg.
Front/Side 0.07 dB
Beamwidth ?
Sidelobe Gain 1.99 dBi @ Az Angle = 176.0 deg.
Front/Sidelobe 0.0 dB

2m antenna pattern
conical (phi) cut at theta = 90 deg. (0 deg.
Elevation); Vertical Polarization is relative to
satellite's XY plane.

144 MHz

Cursor Az 4.0 deg.
Gain 1.99 dBi
0.0 dBmax
0.0 dBmax3D

Aug 5, 2012

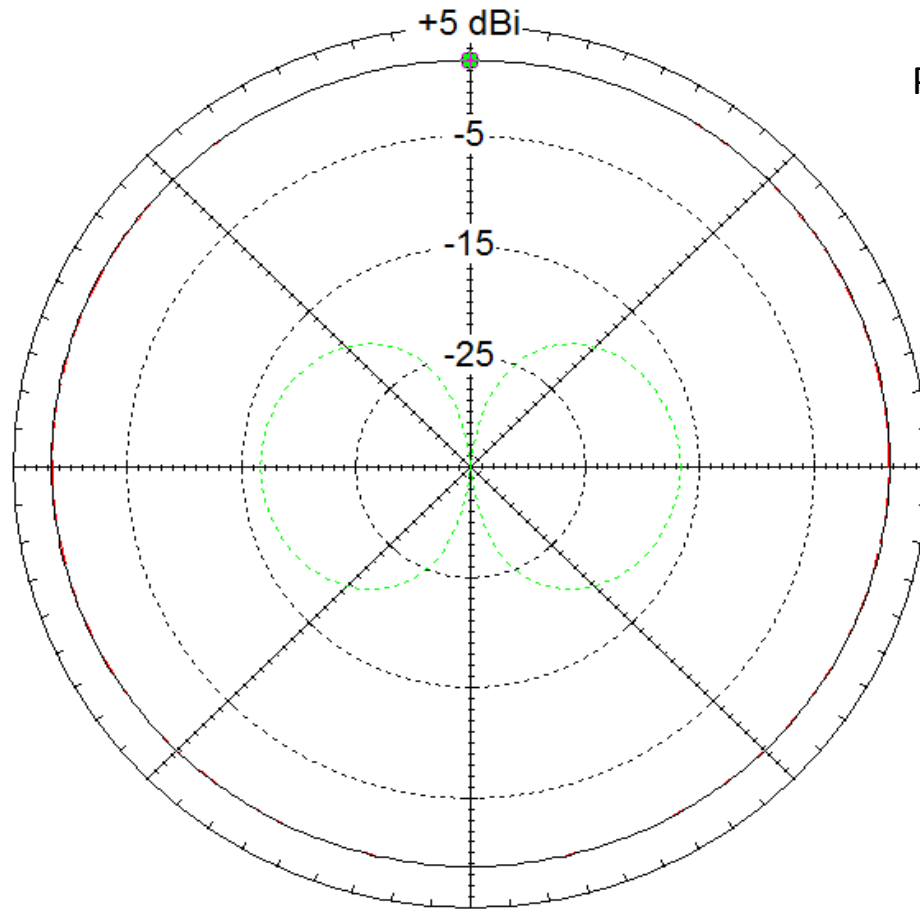
*** Total Field**

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +1.9 dBi



Azimuth Plot
Elevation Angle -15.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.0 dBi
Slice Max Gain 1.87 dBi @ Az Angle = 90.0 deg.
Front/Back 0.65 dB
Beamwidth ?
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

2m antenna pattern
conical (phi) cut at theta = 105 deg. (-15 deg.
Elevation); Vertical Polarization is relative to
satellite's XY plane.

144 MHz

Cursor Az 90.0 deg.
Gain 1.87 dBi
0.0 dBmax
-0.12 dBmax3D

Aug 5, 2012

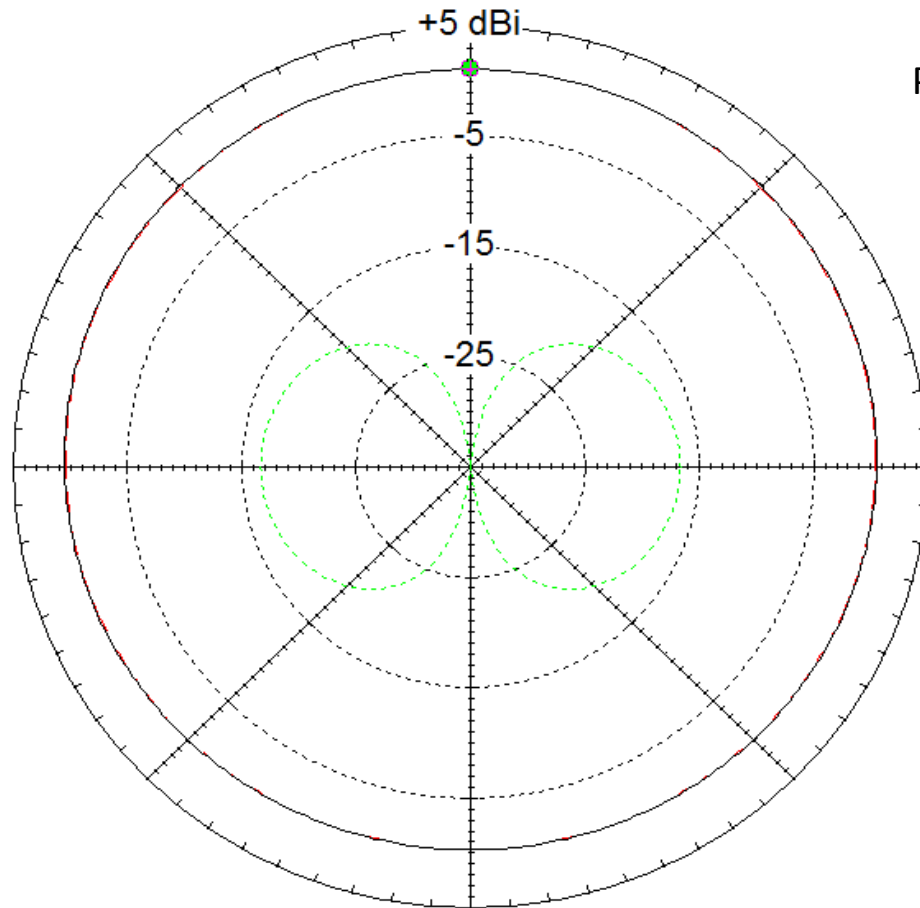
*** Total Field**

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +2.0 dBi



Azimuth Plot
Elevation Angle -30.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 2.0 dBi
Slice Max Gain 1.06 dBi @ Az Angle = 90.0 deg.
Front/Back 1.34 dB
Beamwidth ?
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

2m antenna pattern
conical (phi) cut at theta = 120 deg. (-30 deg.
Elevation); Vertical Polarization is relative to
satellite's XY plane.

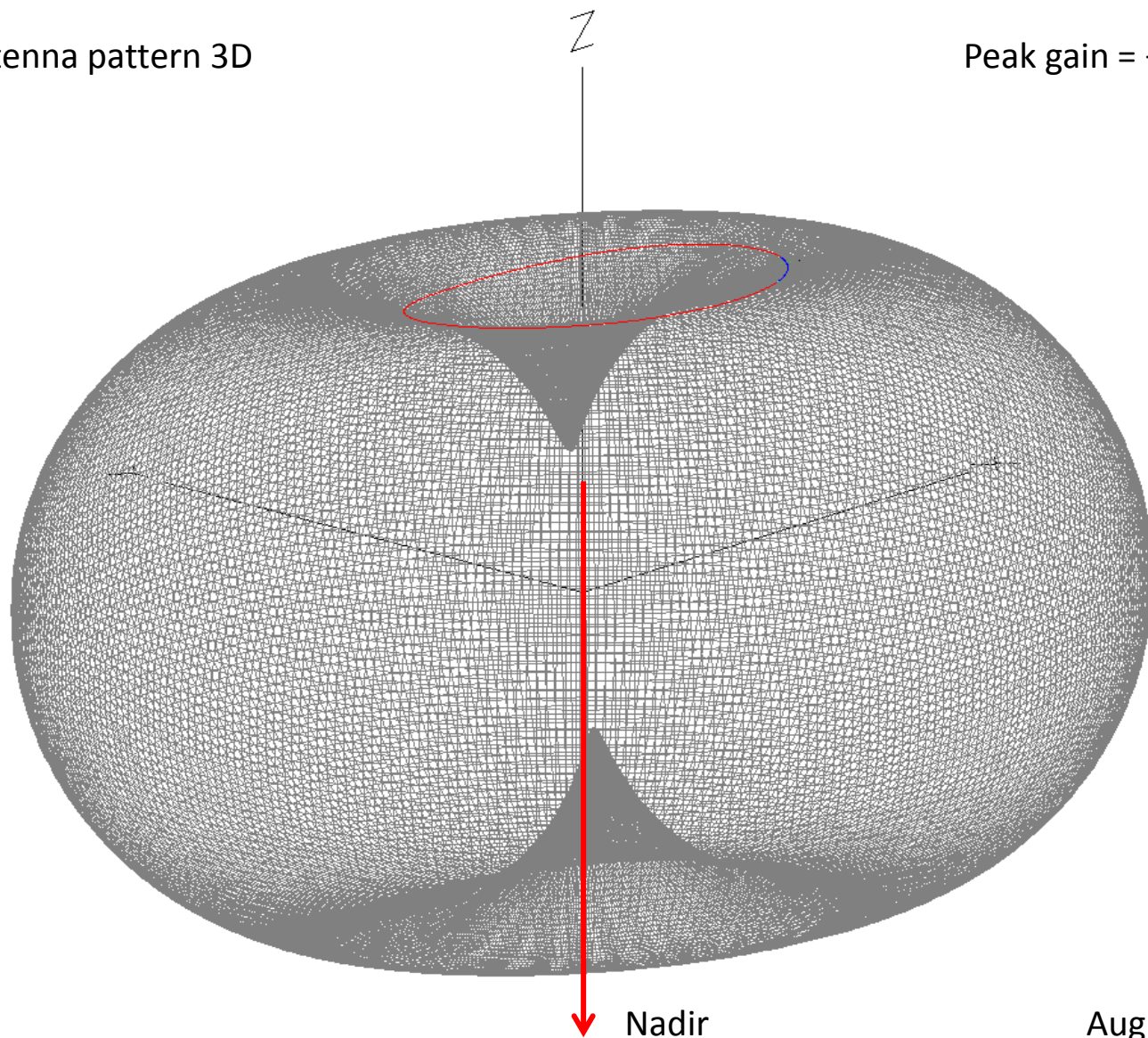
144 MHz

Cursor Az 90.0 deg.
Gain 1.06 dBi
0.0 dBmax
-0.94 dBmax3D

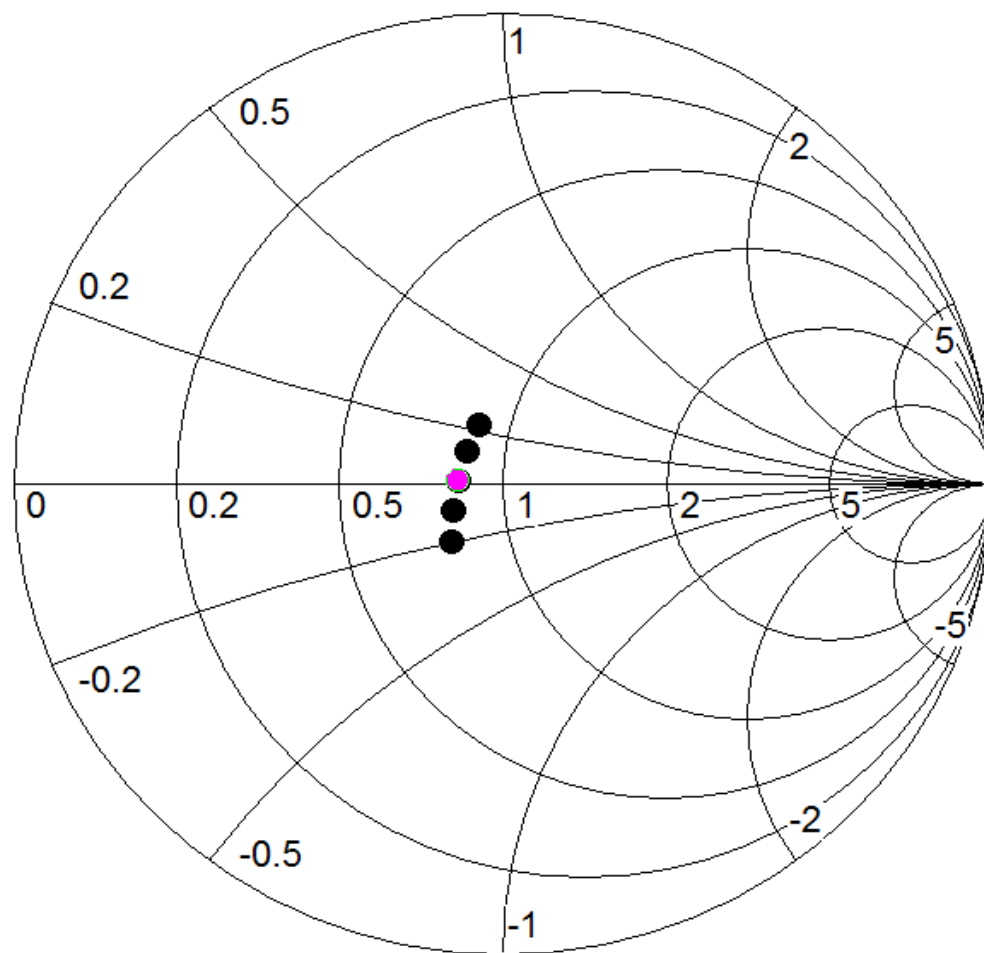
Aug 5, 2012

2m antenna pattern 3D

Peak gain = +2.0 dBi



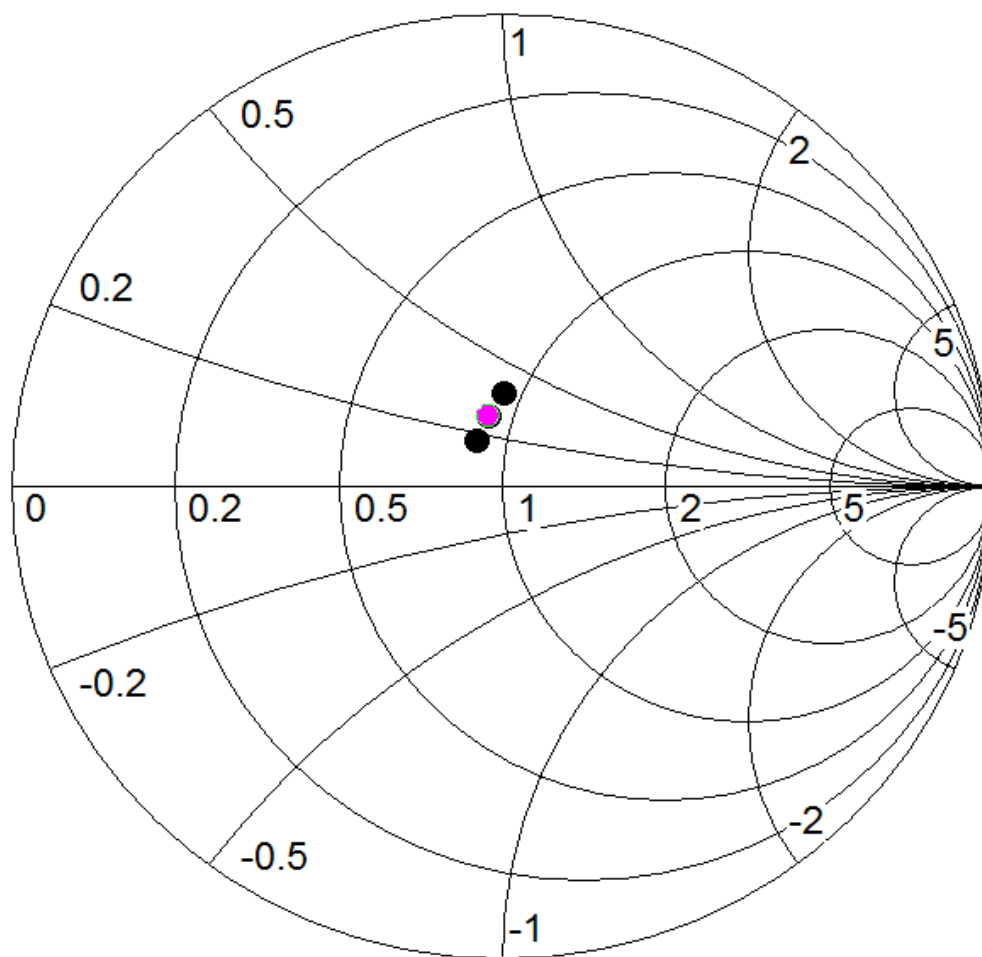
Aug 5, 2012



Freq 146 MHz
 SWR 1.2
 Z 41.59 at 0.94 deg.
 = 41.58 + j 0.6829 ohms
 Refl Coeff 0.09225 at 174.94 deg.
 = -0.09189 + j 0.008142
 Ret Loss 20.7 dB

Base impedance of 598 mm 2 m antenna with the
437 MHz antenna floating (at 146 MHz)

Source # 1
 Z0 50 ohms

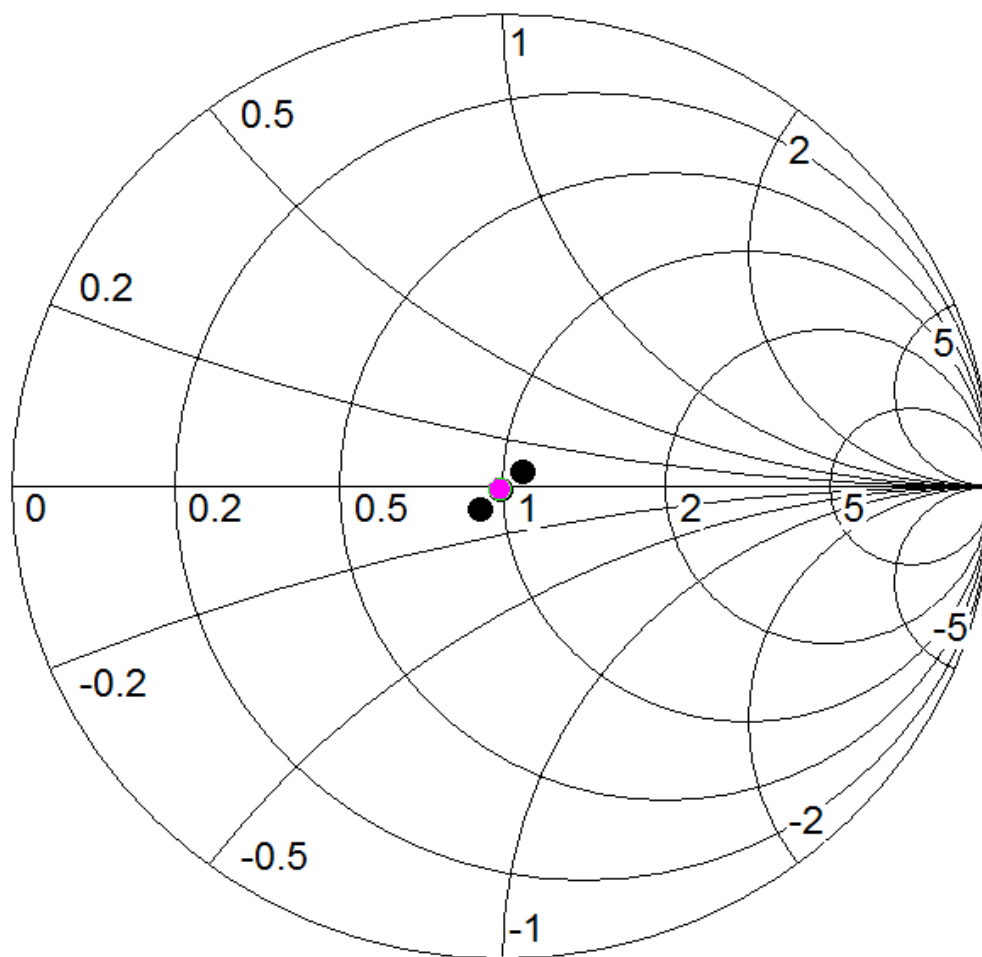


Freq 146 MHz
 SWR 1.36
 Z 47.44 at 16.94 deg.
 = 45.38 + j 13.82 ohms
 Refl Coeff 0.1512 at 100.24 deg.
 = -0.02687 + j 0.1488
 Ret Loss 16.4 dB

Base impedance of 597 mm 2 m antenna with the
437 MHz antenna grounded (at 146 MHz)

Source # 1
 Z0 50 ohms

Aug 5, 2012



Freq 146 MHz
 SWR 1.016
 Z 49.57 at -0.78 deg.
 = 49.57 - j 0.6734 ohms
 Refl Coeff 0.008025 at -122.18 deg.
 = -0.004274 - j 0.006792
 Ret Loss 41.9 dB

Base impedance of 597 mm 2 m antenna with a 7 pF
 shunt capacitor at base of antenna.
 The 437 MHz antenna is grounded (at 146 MHz).

Source # 1
 Z0 50 ohms

Aug 5, 2012

Slides that follow are for the 437 MHz antenna on the +Z edge of the +Y solar panel.

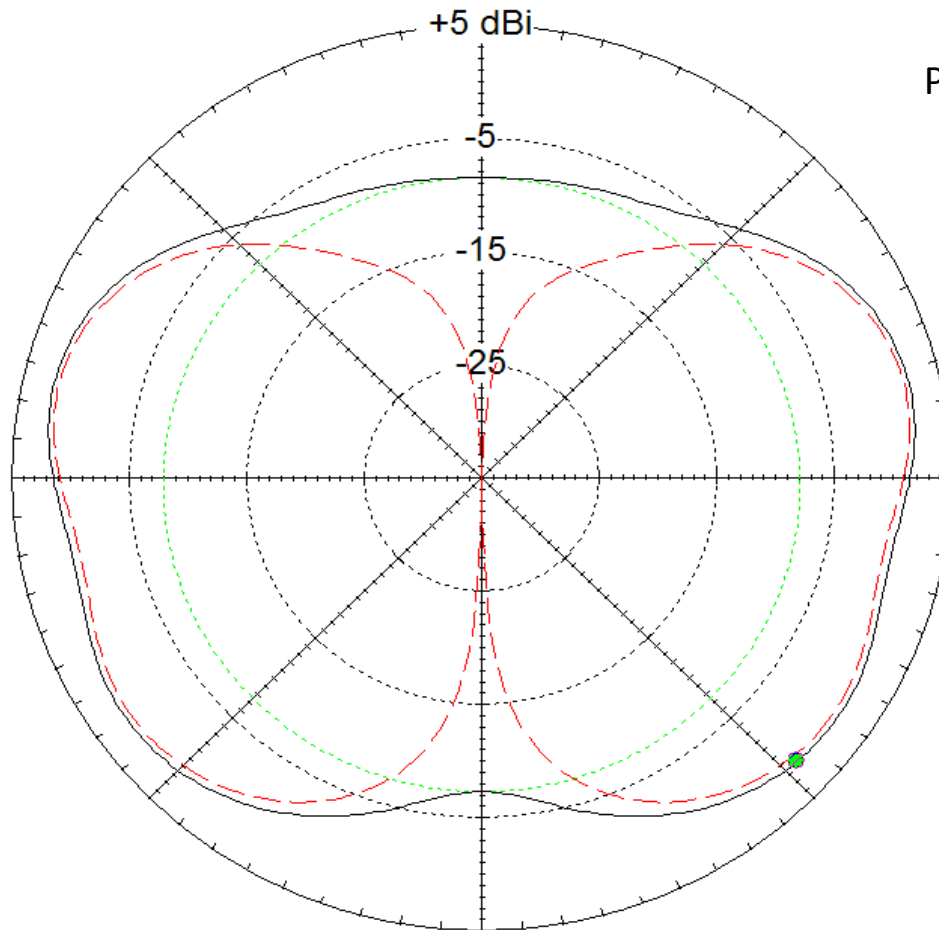
* Total Field

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +2.3 dBi



437 MHz

Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 2.3 dBi @ Elev Angle = 12.0 deg.
Front/Back 1.82 dB
Beamwidth 93.0 deg.; -3dB @ 300.8, 33.8 deg.
Sidelobe Gain 2.3 dBi @ Elev Angle = 167.0 deg.
Front/Sidelobe 0.0 dB

70 cm antenna pattern in XZ plane
(theta cut at phi = 0 deg.)

Vertical Polarization is relative to satellite's XY
plane.

Cursor Elev -43.0 deg.
Gain 1.68 dBi
-0.61 dBmax
-1.64 dBmax3D

Aug 5, 2012

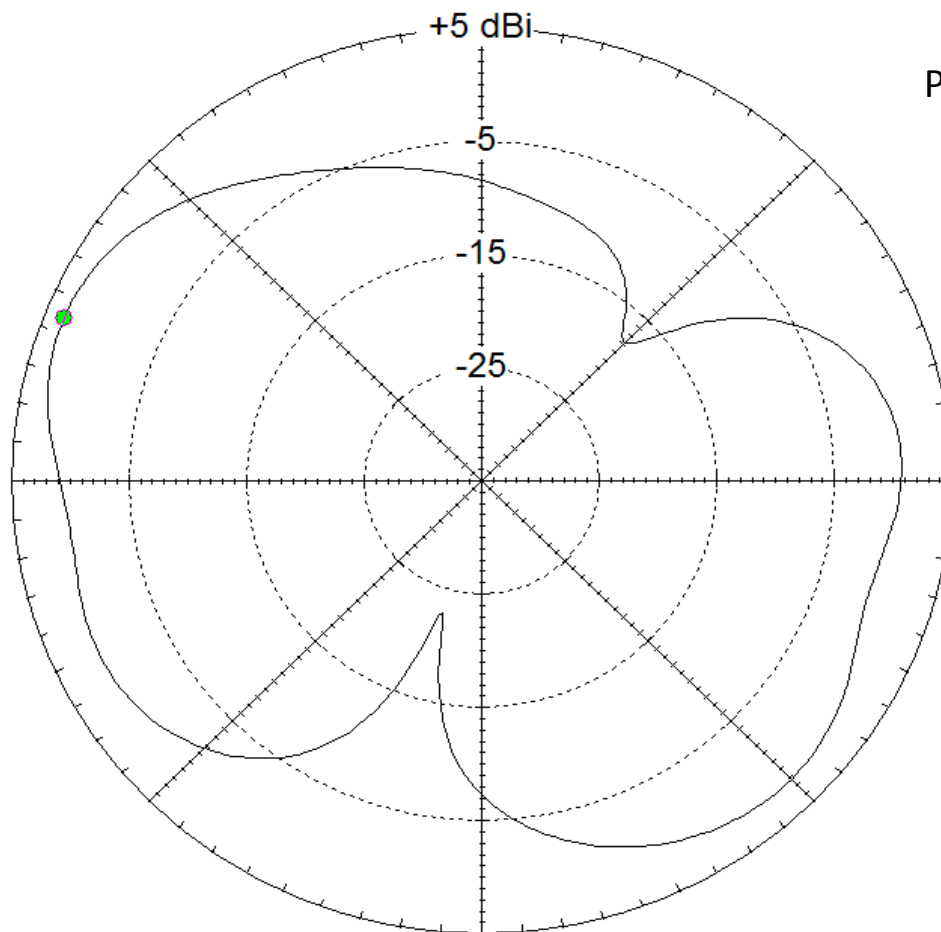
* Total Field

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +3.3 dBi



437 MHz

Elevation Plot
Azimuth Angle 90.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 3.33 dBi @ Elev Angle = 158.0 deg.
Front/Back 3.63 dB
Beamwidth 49.8 deg.; -3dB @ 135.9, 185.7 deg.
Sidelobe Gain 2.26 dBi @ Elev Angle = 314.0 deg.
Front/Sidelobe 1.07 dB

70 cm antenna pattern in YZ plane
(theta cut at phi = 90 deg.)

Vertical Polarization is relative to satellite's XY plane.

Cursor Elev 158.0 deg.
Gain 3.33 dBi
0.0 dBmax
0.0 dBmax3D

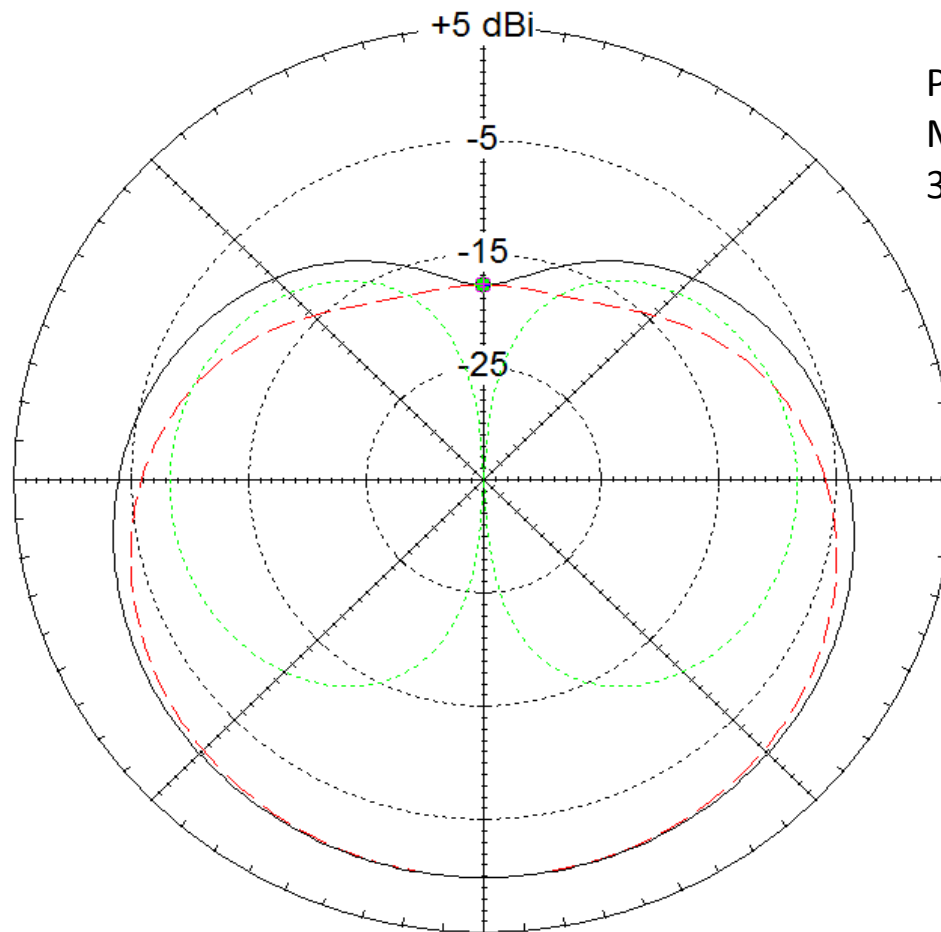
Aug 5, 2012

* Total Field

EZNEC+

Horizontal Pol

Vertical Pol



Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

437 MHz

Azimuth Plot
Elevation Angle 45.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 0.11 dBi @ Az Angle = 270.0 deg.
Front/Back 17.88 dB
Beamwidth 156.2 deg.; -3dB @ 191.9, 348.1 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

70 cm antenna pattern
conical (phi) cut at theta = 45 deg. (45 deg.
elevation)

Cursor Az 90.0 deg.
Gain -17.77 dBi
-17.88 dBmax
-21.1 dBmax3D

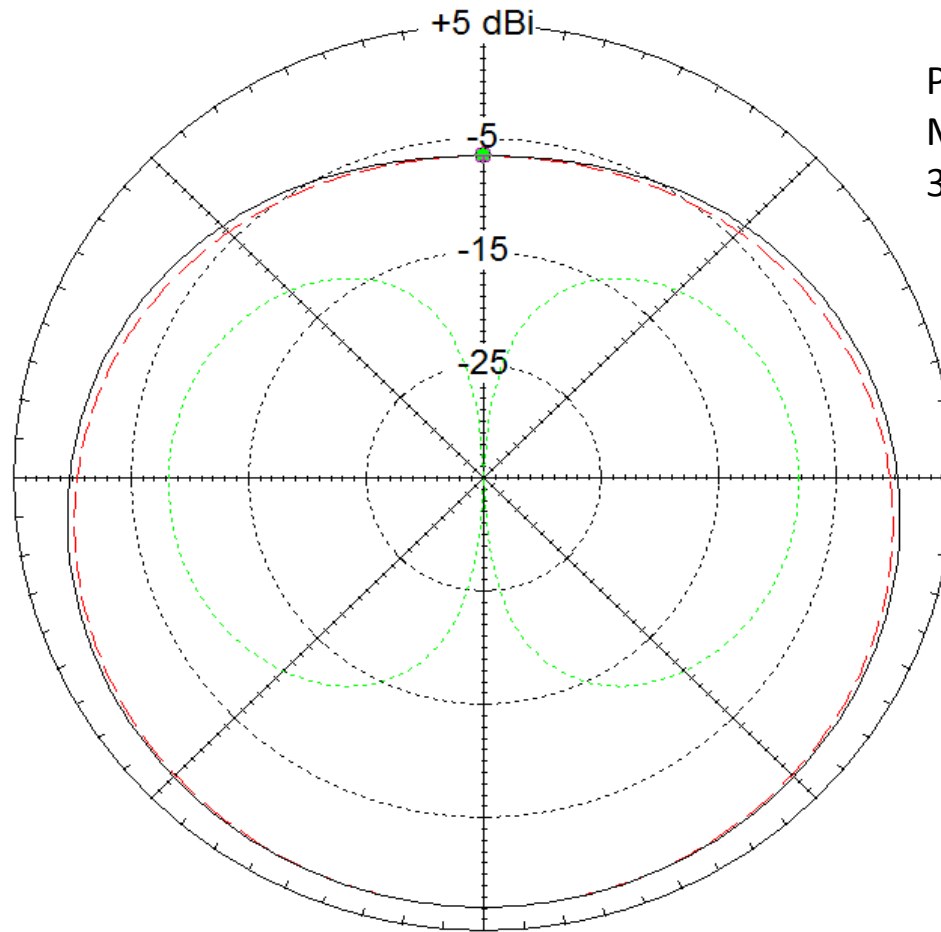
Aug 5, 2012

* Total Field

EZNEC+

Horizontal Pol

Vertical Pol



Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

437 MHz

Azimuth Plot
Elevation Angle 30.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 2.88 dBi @ Az Angle = 270.0 deg.
Front/Back 9.47 dB
Beamwidth 190.2 deg.; -3dB @ 174.9, 5.1 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

70 cm antenna pattern
conical (phi) cut at theta = 60 deg. (30 deg.
elevation)

Cursor Az 90.0 deg.
Gain -6.59 dBi
-9.47 dBmax
-9.92 dBmax3D

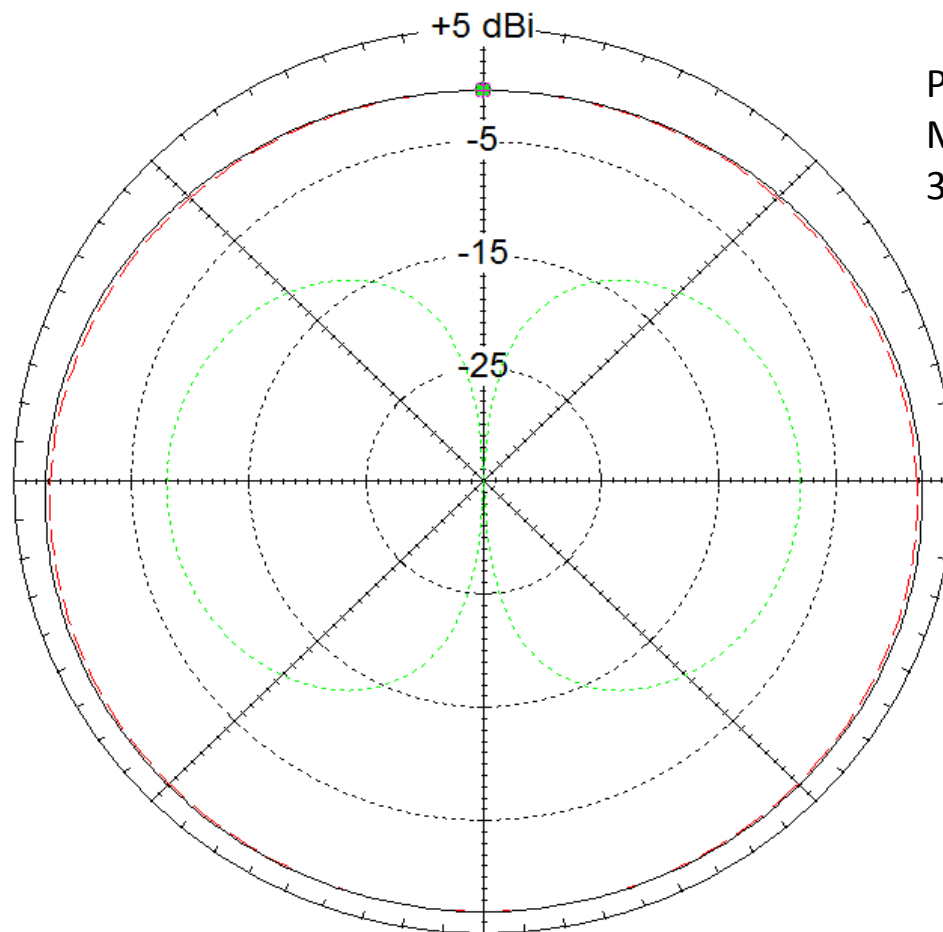
Aug 5, 2012

* Total Field

EZNEC+

Horizontal Pol

Vertical Pol



Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

437 MHz

Azimuth Plot
Elevation Angle 15.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 3.03 dBi @ Az Angle = 270.0 deg.
Front/Back 3.58 dB
Beamwidth 298.6 deg.; -3dB @ 120.7, 59.3 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

70 cm antenna pattern
conical (phi) cut at theta = 75 deg. (15 deg.
elevation)

Cursor Az 90.0 deg.
Gain -0.55 dBi
-3.58 dBmax
-3.88 dBmax3D

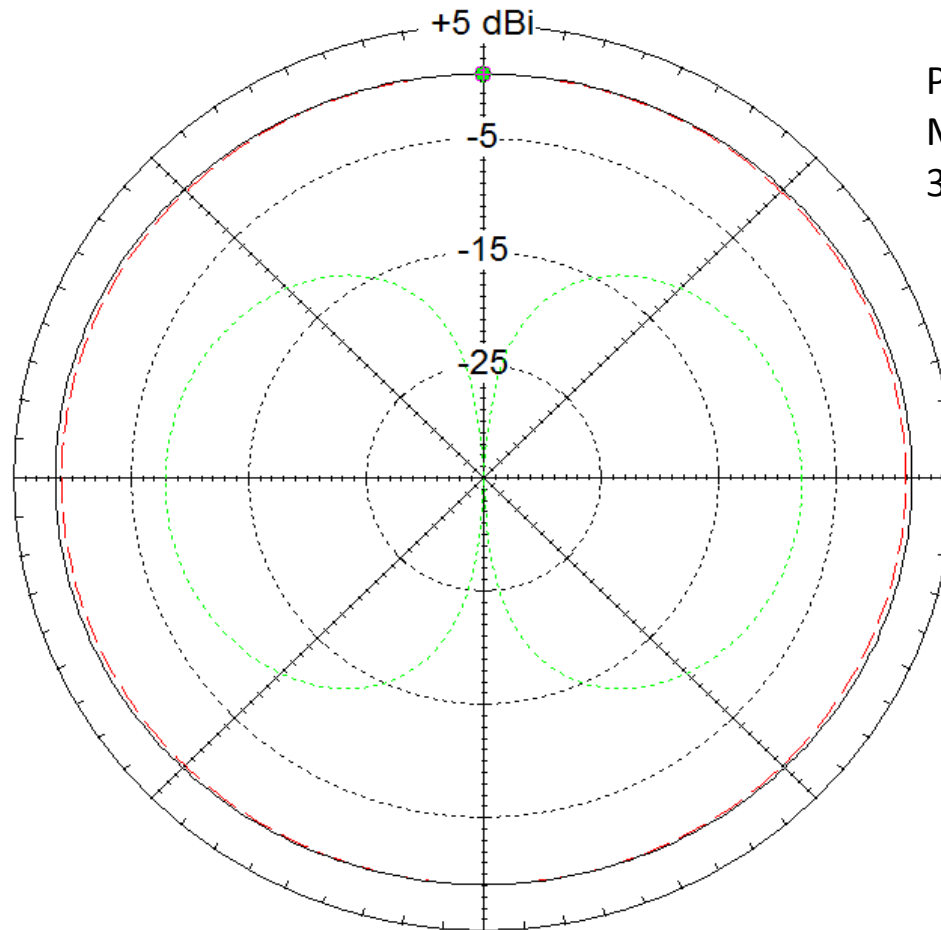
Aug 5, 2012

* Total Field

EZNEC+

Horizontal Pol

Vertical Pol



Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

437 MHz

Azimuth Plot
Elevation Angle 0.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 1.45 dBi @ Az Angle = 186.0 deg.
Front/Back 0.03 dB
Beamwidth ?
Sidelobe Gain 1.45 dBi @ Az Angle = 354.0 deg.
Front/Sidelobe 0.0 dB

70 cm antenna pattern
conical (phi) cut at theta = 90 deg. (0 deg.
elevation)

Cursor Az 90.0 deg.
Gain 0.67 dBi
-0.78 dBmax
-2.66 dBmax3D

Aug 5, 2012

* Total Field

EZNEC+

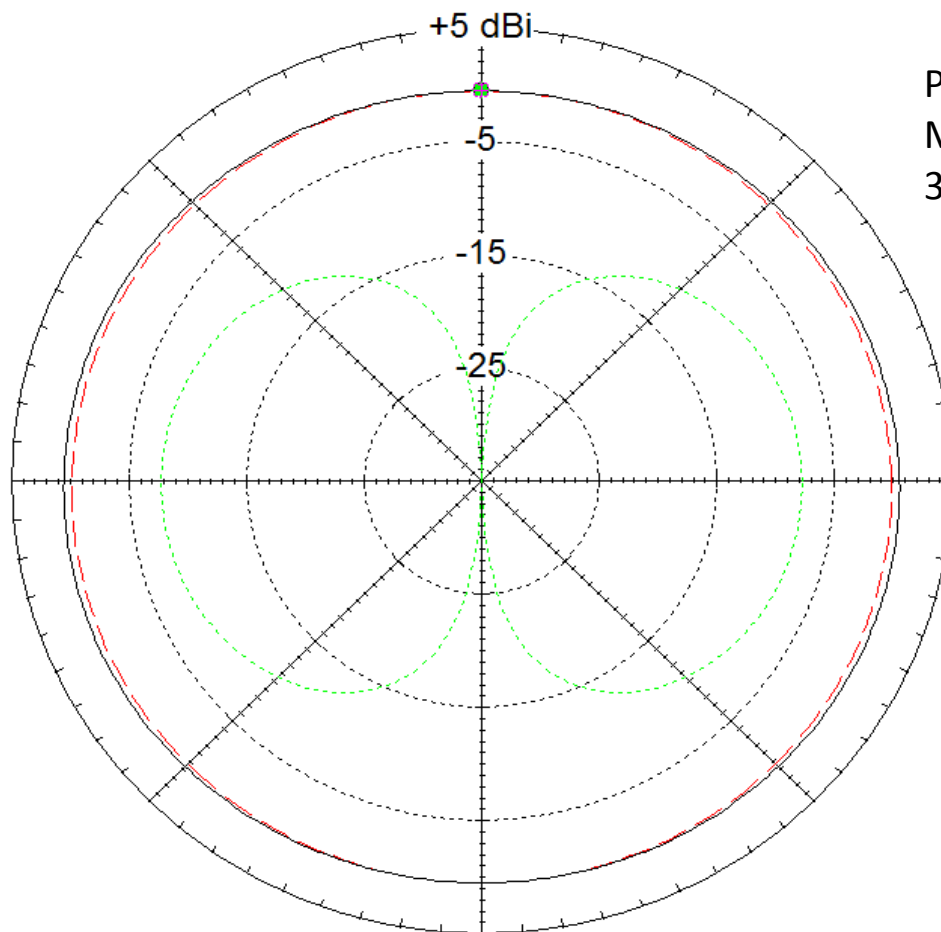
Horizontal Pol

Vertical Pol

Peak gain = +2.3 dBi

Min. Gain = -1.6 dBi

3.9 dB variation



437 MHz

Azimuth Plot
Elevation Angle -15.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 0.71 dBi @ Az Angle = 210.0 deg.
Front/Back 0.62 dB
Beamwidth ?
Sidelobe Gain 0.71 dBi @ Az Angle = 330.0 deg.
Front/Sidelobe 0.0 dB

70 cm antenna pattern
conical (phi) cut at theta = 105 deg. (-15 deg.
elevation

Cursor Az 90.0 deg.
Gain -0.59 dBi
-1.3 dBmax
-3.91 dBmax3D

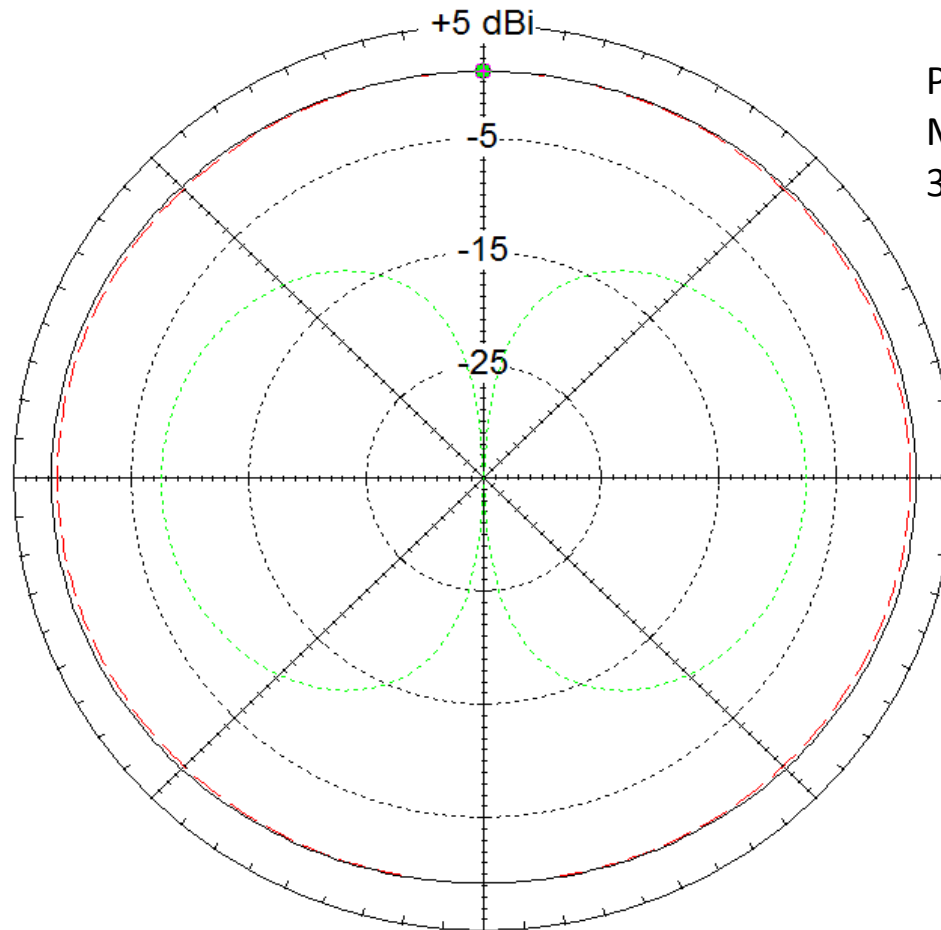
Aug 5, 2012

* Total Field

EZNEC+

Horizontal Pol

Vertical Pol



Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

437 MHz

Azimuth Plot
Elevation Angle -30.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 1.77 dBi @ Az Angle = 358.0 deg.
Front/Side 0.89 dB
Beamwidth ?
Sidelobe Gain 1.77 dBi @ Az Angle = 182.0 deg.
Front/Sidelobe 0.0 dB

70 cm antenna pattern
conical (phi) cut at theta = 120 deg. (-30 deg.
elevation

Cursor Az 90.0 deg.
Gain 0.88 dBi
-0.89 dBmax
-2.45 dBmax3D

Aug 5, 2012

* Total Field

EZNEC+

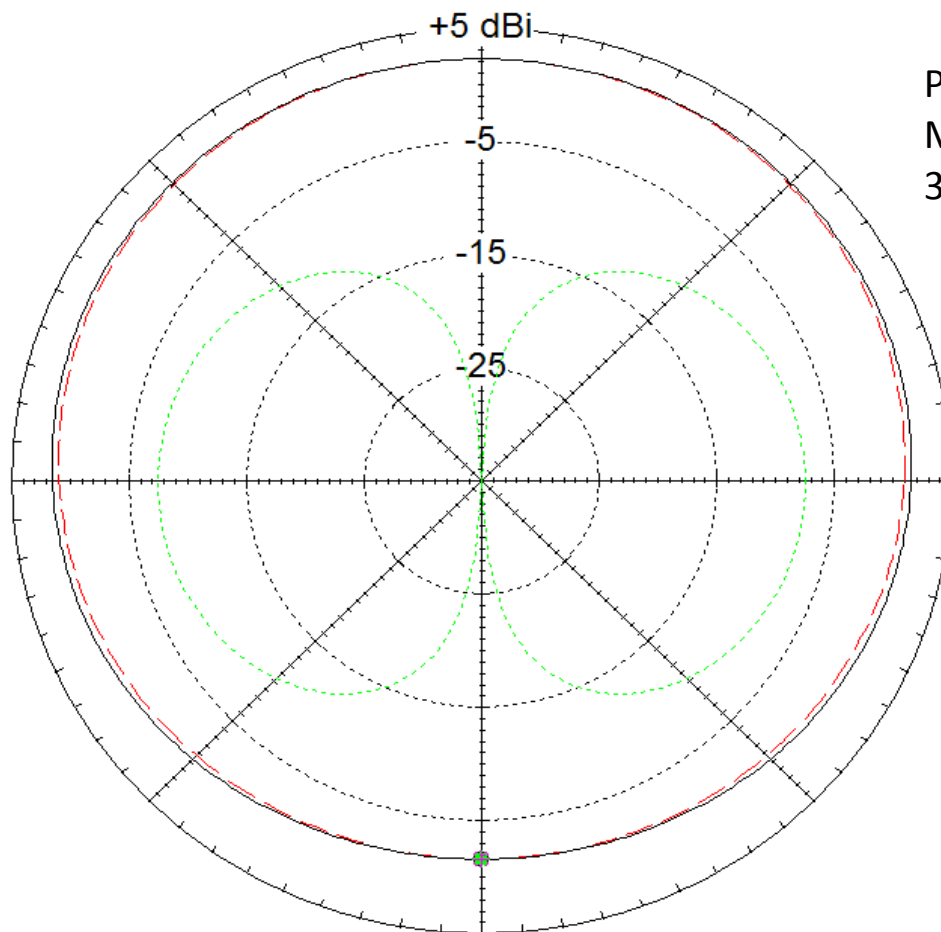
Horizontal Pol

Vertical Pol

Peak gain = +2.3 dBi

Min. Gain = -1.6 dBi

3.9 dB variation



437 MHz

Azimuth Plot
Elevation Angle -45.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 2.25 dBi @ Az Angle = 90.0 deg.
Front/Back 3.86 dB
Beamwidth 292.5 deg.; -3dB @ 303.7, 236.2 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

70 cm antenna pattern
conical (phi) cut at theta = 135 deg. (-45 deg.
elevation

Cursor Az 270.0 deg.
Gain -1.61 dBi
-3.86 dBmax
-4.93 dBmax3D

Aug 5, 2012

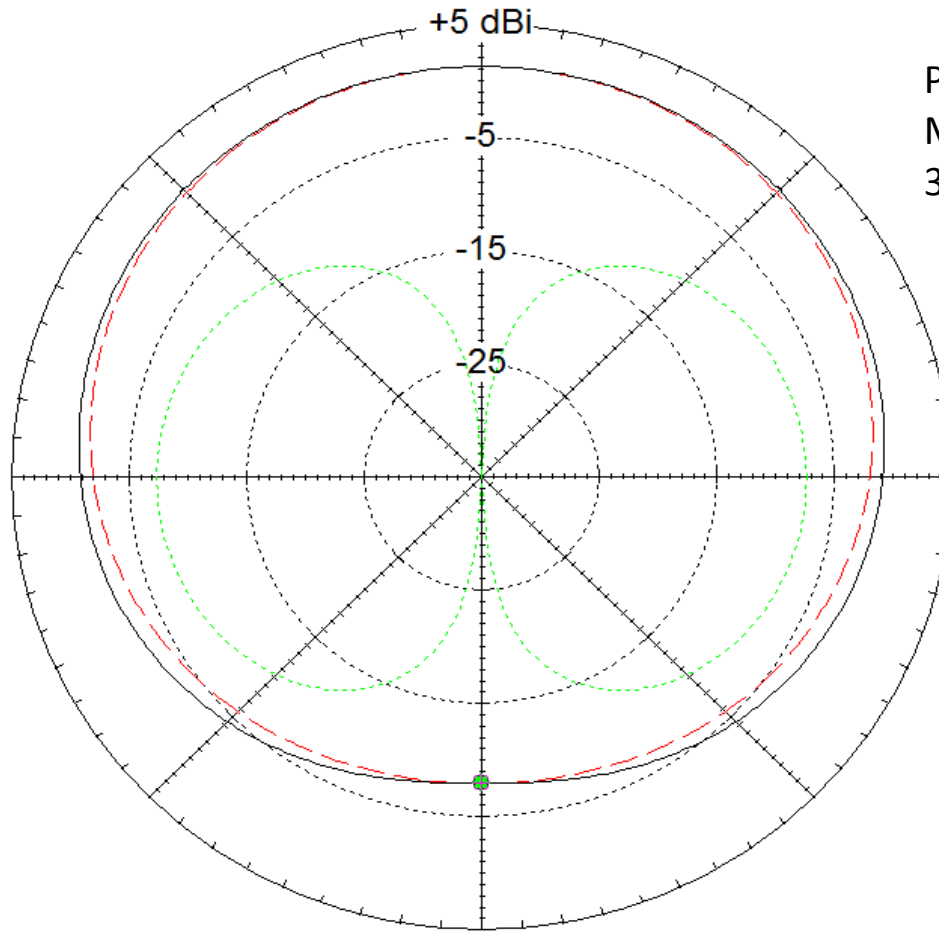
* Total Field

EZNEC+

Horizontal Pol

Vertical Pol

Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation



437 MHz

Azimuth Plot
Elevation Angle -60.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain 1.24 dBi @ Az Angle = 90.0 deg.
Front/Back 9.16 dB
Beamwidth 208.4 deg.; -3dB @ 345.8, 194.2 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

70 cm antenna pattern
conical (phi) cut at theta = 150 deg. (-60 deg. Elevation)

Cursor Az 270.0 deg.
Gain -7.92 dBi
-9.16 dBmax
-11.25 dBmax3D

Aug 5, 2012

* Total Field

EZNEC+

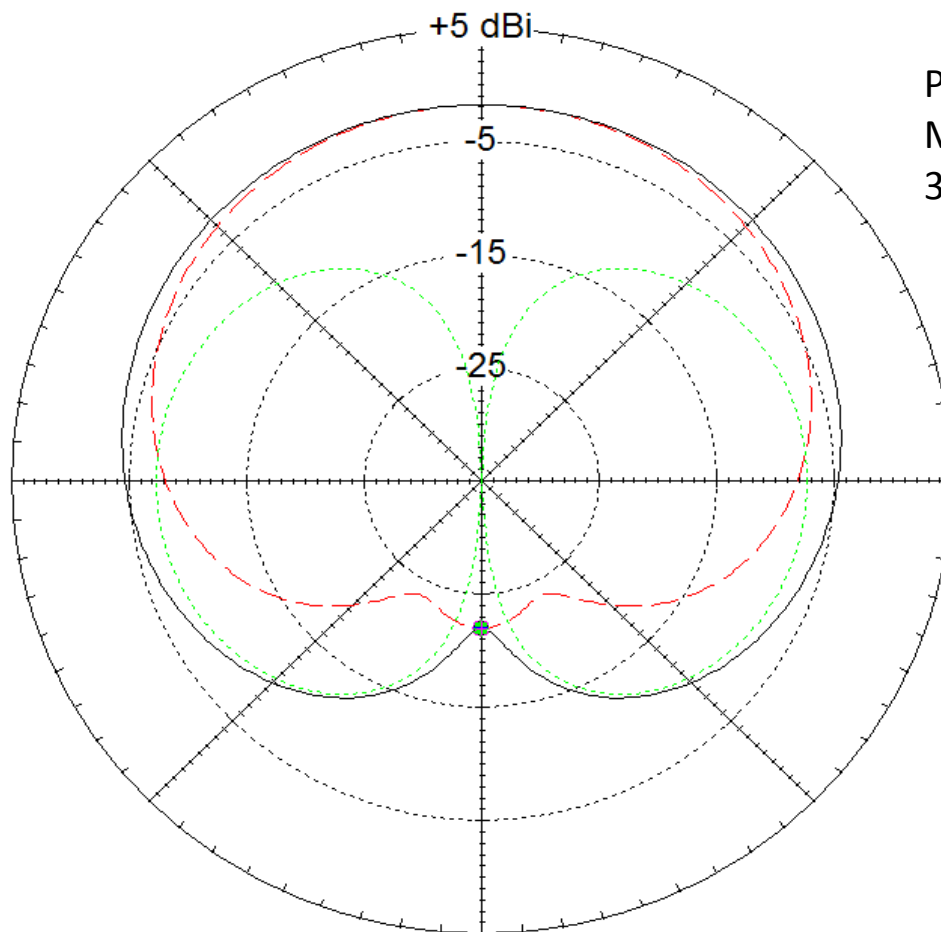
Horizontal Pol

Vertical Pol

Peak gain = +2.3 dBi

Min. Gain = -1.6 dBi

3.9 dB variation



437 MHz

Azimuth Plot
Elevation Angle -75.0 deg.
Outer Ring 5.0 dBi

3D Max Gain 3.33 dBi
Slice Max Gain -1.82 dBi @ Az Angle = 90.0 deg.
Front/Back 20.18 dB
Beamwidth 183.5 deg.; -3dB @ 358.2, 181.7 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

70 cm antenna pattern
conical (phi) cut at theta = 165 deg. (-75 deg. Elevation)

Cursor Az 270.0 deg.
Gain -22.0 dBi
-20.18 dBmax
-25.32 dBmax3D

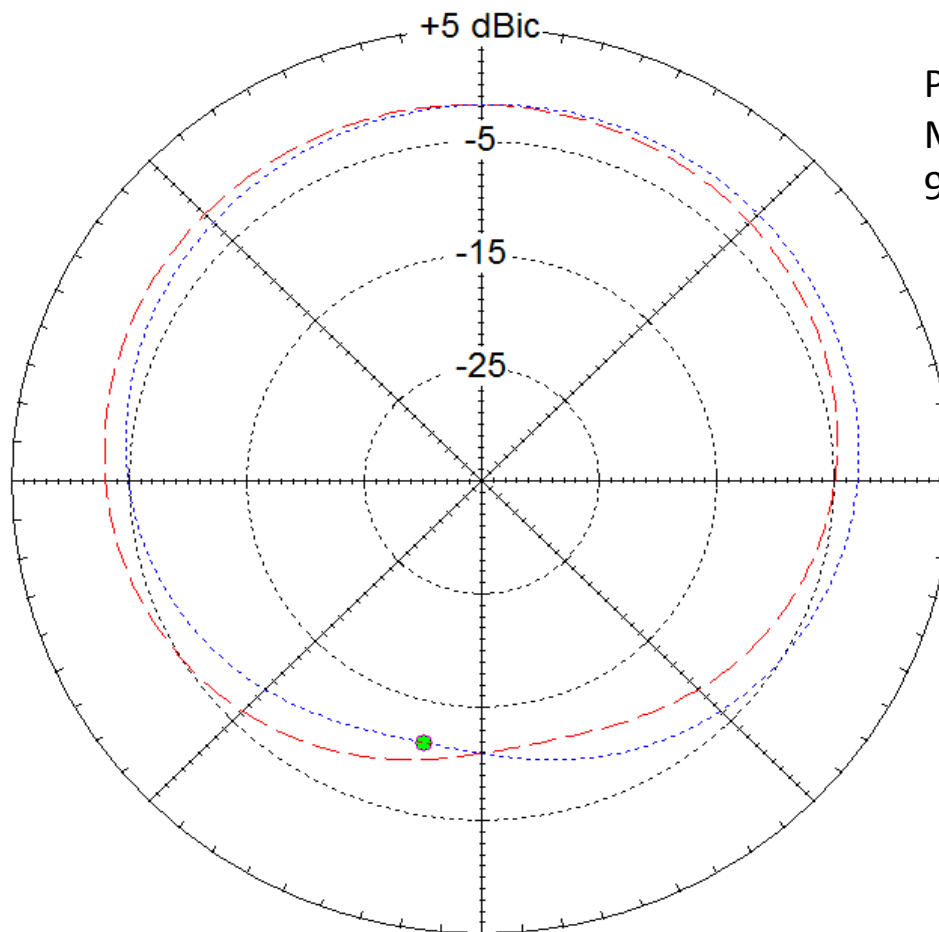
Aug 5, 2012

* RH Circular Pol

LH Circular Pol

EZNEC+

Peak gain = -1.7 dBi
Min. Gain = -11.4 dBi
9.7 dB variation



437 MHz

Azimuth Plot
Elevation Angle -60.0 deg.
Outer Ring 5.0 dBic

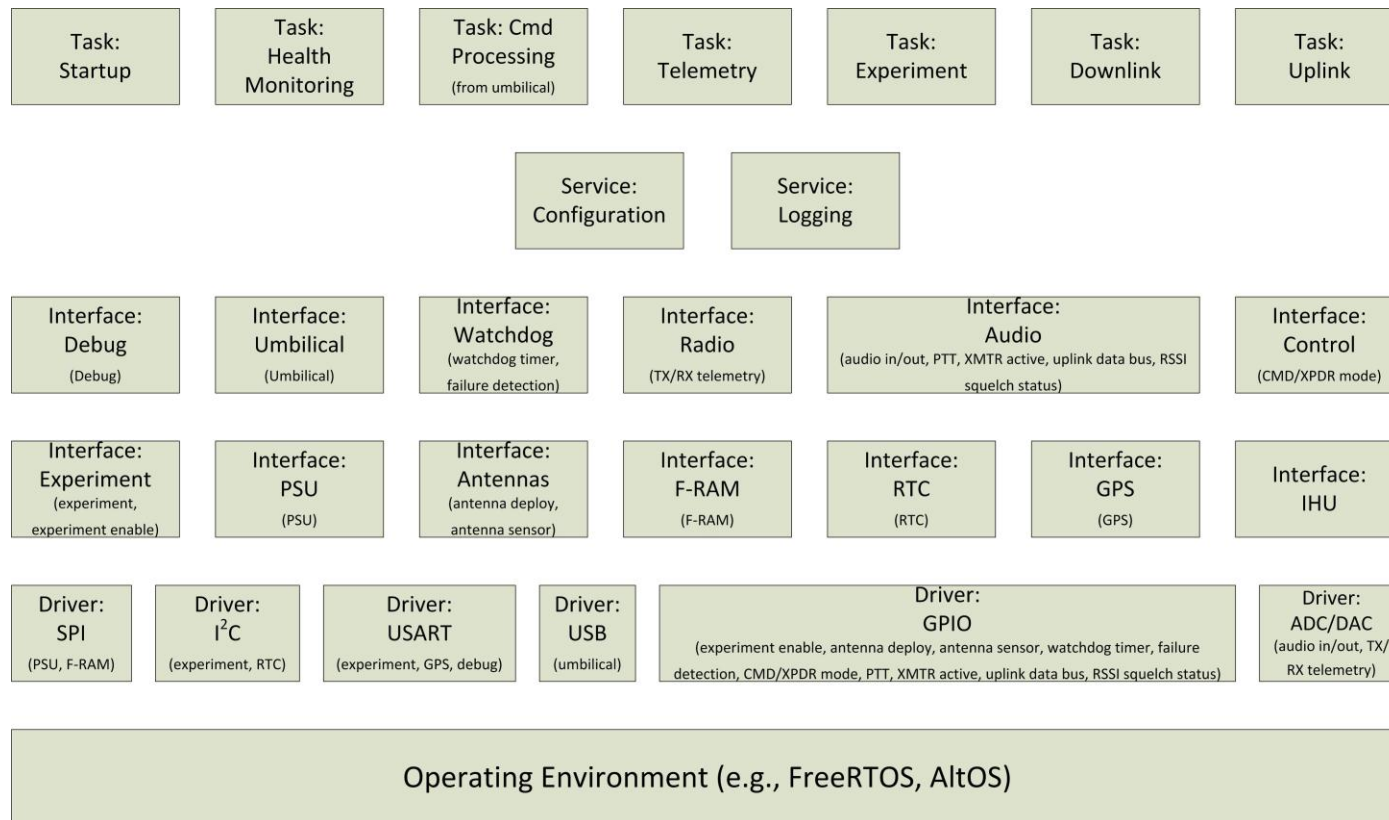
3D Max Gain 0.32 dBic
Slice Max Gain -1.63 dBic @ Az Angle = 65.0 deg.
Front/Back 9.24 dB
Beamwidth 201.1 deg.; -3dB @ 333.9, 175.0 deg.
Sidelobe Gain < -100 dBic
Front/Sidelobe > 100 dB

70 cm RHCP and LHCP antenna pattern
conical (phi) cut at theta = 150 deg. (-60 deg. Elevation)

Cursor Az 258.0 deg.
Gain -11.36 dBic
-9.73 dBmax
-11.68 dBmax3D

FOX1 IHU SOFTWARE COMPONENTS

Version 1.0, April 1, 2012



Fox-1 Downlink Power Amplifier Prototype



Measurement results

Marc Franco, N2UO

August 17, 2012

Power supply voltage sweep

Frequency: 145.9 MHz

Temp.: 25°C

Pin: 12 dBm

Vcc	Current [mA]	Pout [dBm]	Pout [W]	Pdc [W]	Eff [%]
3.2	169	26.32	0.429	0.541	79.2
3.3	174	26.56	0.453	0.574	78.9
3.4	179	26.81	0.480	0.609	78.8
3.5	184	27.05	0.507	0.644	78.7
3.6	190	27.28	0.535	0.684	78.2
3.7	195	27.51	0.564	0.722	78.1
3.8	200	27.7	0.589	0.760	77.5
3.9	206	27.92	0.619	0.803	77.1
4	211	28.13	0.650	0.844	77.0
4.1	215	28.29	0.675	0.882	76.5
4.2	221	28.49	0.706	0.928	76.1

Temperature testing

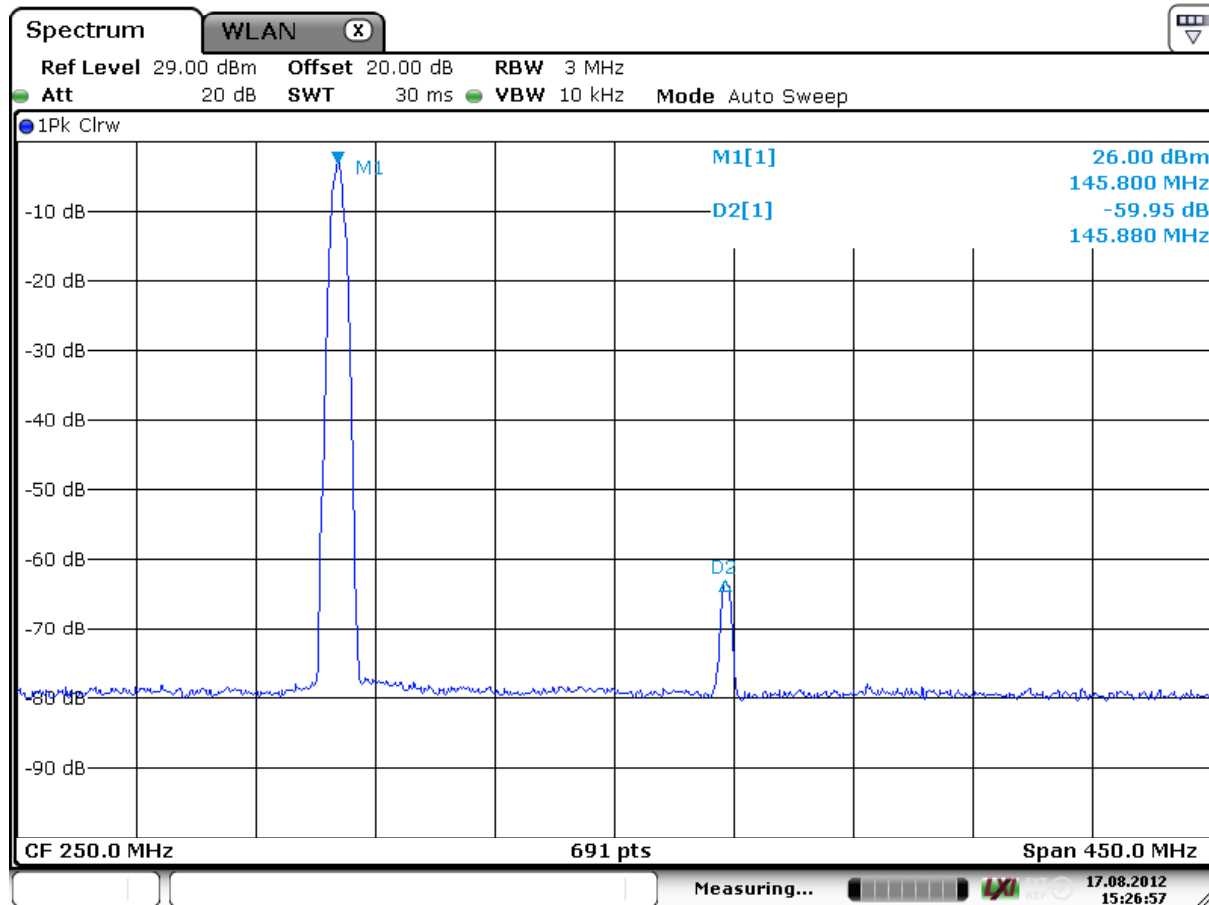
Frequency: 145.9 MHz

Vcc: 3.3 V

Pin: 12 dBm

Temp [°C]	2nd harm. [dBc]	Current [mA]	Pout [dBm]	Pout [W]	Pdc [W]	Eff [%]
-40	-59.4	181	26.92	0.492	0.597	82.4
25	-60.8	174	26.56	0.453	0.574	78.9
85	-60	166	26.19	0.416	0.548	75.9

Output spectrum



Date: 17.AUG.2012 15:26:56

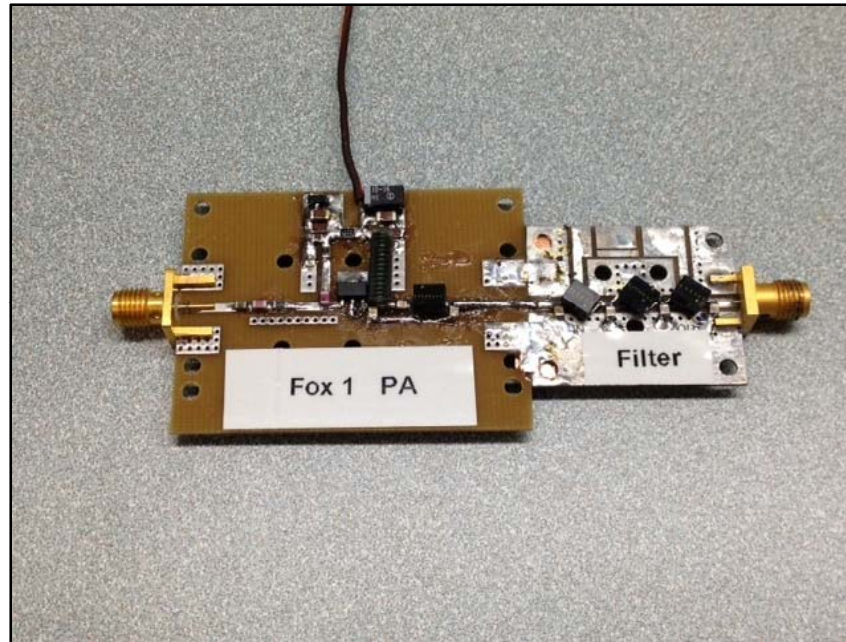
- The third harmonic is guaranteed to be at least -75 dBc (below measurement capability)

Ruggedness and stability

- Test conditions:
 - V_{cc} : 3.3 to 4.2 V
 - P_{in} : 12 dBm
 - Load mismatch: short circuit, open circuit, various values in between
- Results:
 - No failure or degradation in performance after tests
 - No oscillations or spurs observed

Future work

- Awaiting exciter board to perform interface with the amplifier
- A driver stage may be needed
- After integration is complete, more environmental and performance tests will be performed
- Final PCB layout, schematic and bill of materials will be generated after all the tests are complete



- Hand assembled prototype using existing PC boards

Receiving FOX-1 Satellite on 2 meters

Satellite Transmitter

Power	400.00 mW	minimum
Power (dBm0)	26.02 dBm0	
Antenna Gain	1.00 dBi	
EIRP	27.02 dBm0	

Path Loss

Orbit Altitude	650.00 Km	
Earth Radius	6378.00 Km	
Elevation Angle	10.00 degrees	= 0.174533 radians
Slant Range @ 0°	2951.93 Km	
Slant Range @ elevation angle	2045.33 Km	10.00 degrees
Slant Range @ 90°	650.00 Km	
Frequency	145.90 MHz	
wavelength	2.06E-03 Km	2 meters
Path Loss @ 0° elevation	-145.13 dB	
Path Loss @ elevation angle	-141.94 dB	10.00 degrees
Path Loss @ 90° elevation	-131.98 dB	

Ground Station

Antenna Gain	8.00 dBi	hand held "Arrow" antenna as measured by Central States VHF society
Rx Signal Level @ 0° elevation	-110.10 dB	
Rx Signal Level @ elevation angle	-106.92 dB	
Rx Signal Level @ 90° elevation	-96.96 dB	

Noise

Antenna Temperature	1000 K	
Receiver Noise Figure	6.00 dB	Kenwood D7 HT -122 dBm for 12 dB SINAD
Receiver Noise Temperature	864.51 K	
Total System Noise Temp	1864.51 K	
Receiver Bandwidth	15000.00 Hz	
Boltzmanns constant	1.38E-23 J/K	
Noise Power	3.86E-16 W	
Rx Noise Level	-124.13 dBm0	

Carrier to Noise Ratio

0° elevation	14.03 dB	
@ elevation angle	17.22 dB	10.00 degrees
90° elevation	27.17 dB	
C/N for 12 dB SINAD	4.00 dB	Kenwood D7 HT -122 dBm for 12 dB SINAD

Link Margin

0° elevation	10.03 dB	
@ elevation angle	13.22 dB	10.00 degrees
90° elevation	23.17 dB	

Fox-1 Experimental Payload

AMSAT

Faculty Advisor: Steven Strom

CoAdvisors: George Walters, Chris Coulston

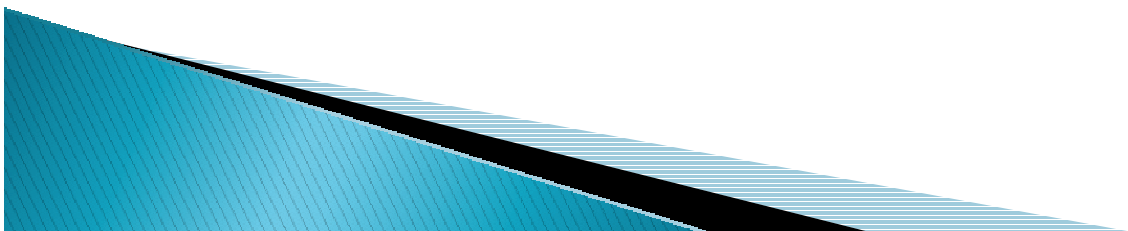
Industrial Supervisor: Alexander Harvilchuck

Industry Sponsor: IBM

Mike Corona

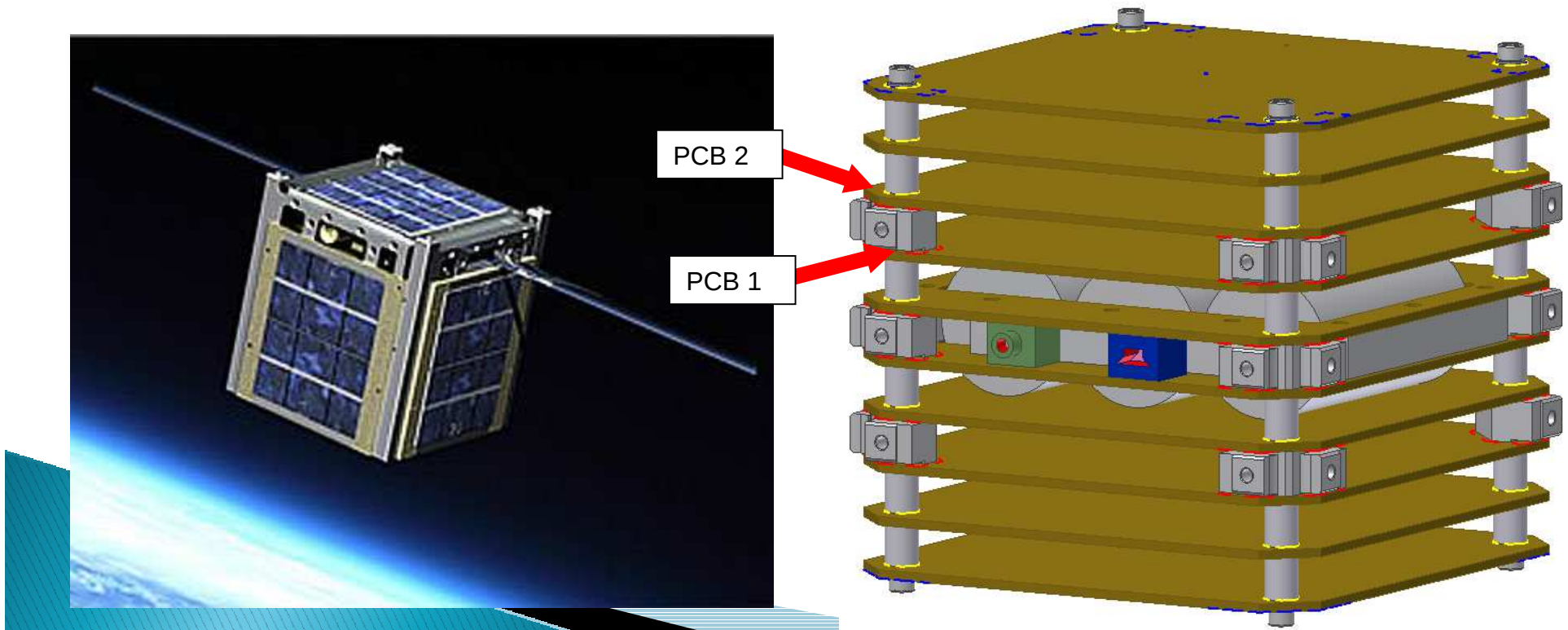
Brandon Marvenko

Edward Pizzella



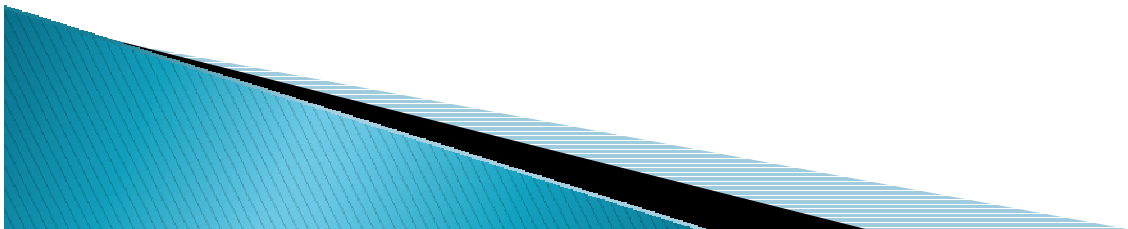
Introduction

- ▶ What is AMSAT?
- ▶ What is the experimental payload?
- ▶ NASA accepted
 - Fox Satellite project participating in the ELaNa program



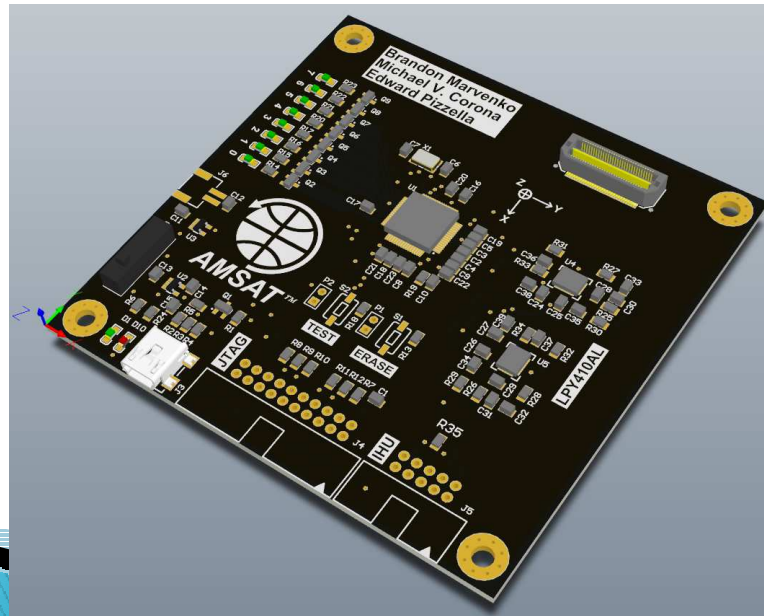
Engineering Requirements

- ▶ Receive and interpret commands from the IHU (Internal Housekeeping Unit) via SPI
- ▶ Average power consumption will not exceed 200mW
- ▶ Measure Spin Rate, Deviation, Up Time
- ▶ Respond correctly to IHU commands: Reset and Send
- ▶ PCB will conform to the internal dimensions of the 1U CubeSat chassis (10x10x10 cm)
- ▶ Withstand the launch and space conditions

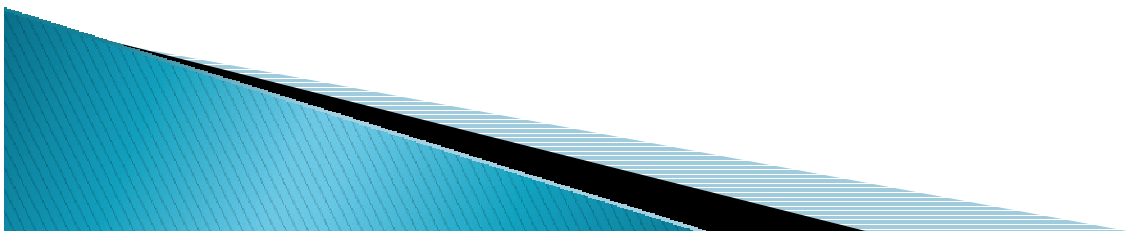
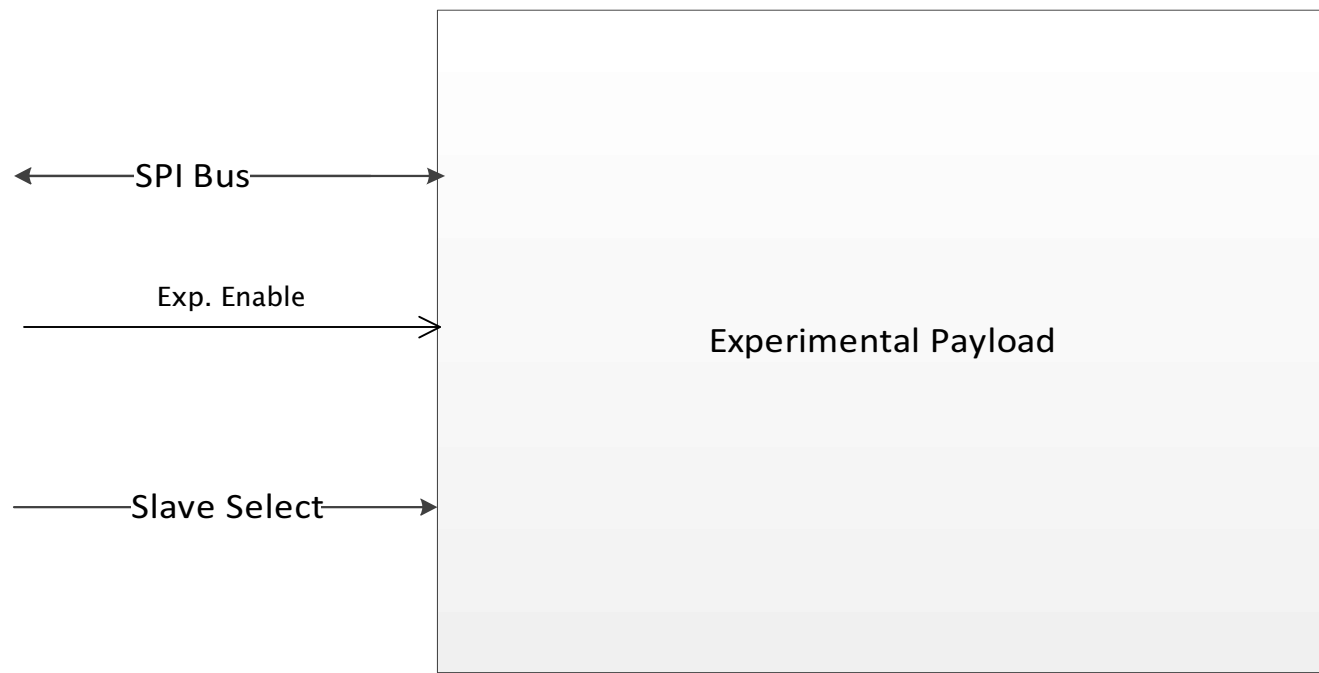


Design (Hardware)

- ▶ **Completed Prototype**
 - AT91SAM7 MCU
 - Various Interface Headers
 - Multiple Power Sources
 - Indicator LEDs
 - Two MEMS Gyros
 - J-TAG Header
- ▶ **In Progress Flight Board**
 - Final PCB
 - Similar to prototype
 - Four MEMS gyros for redundancy
 - Only high speed board-to-board connectors

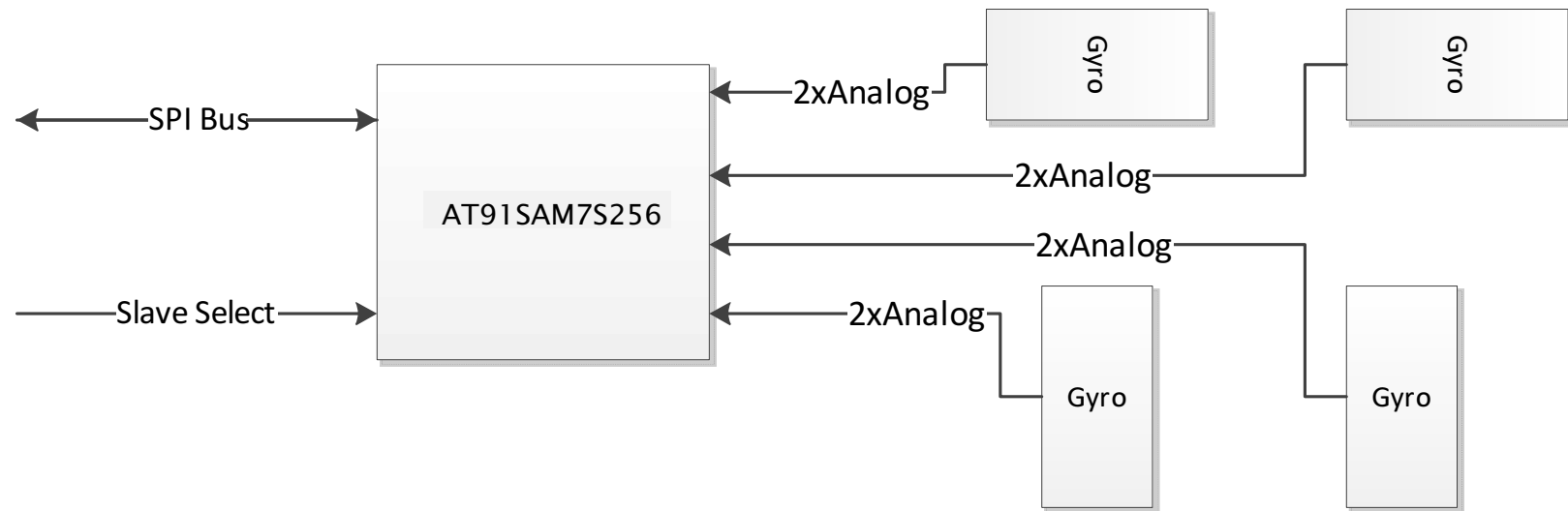


Design – Level 0

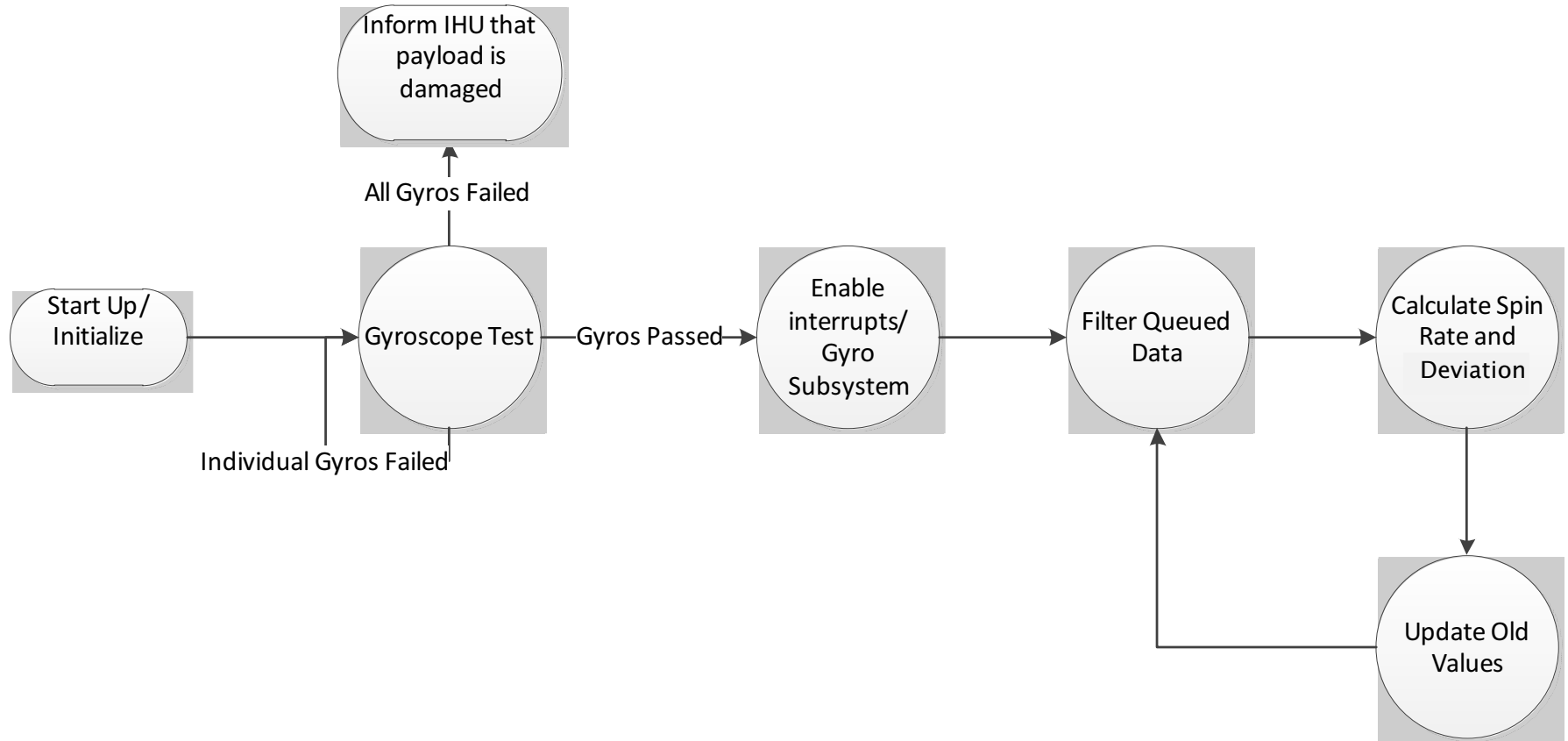


Design – Level 1

- ▶ ARM Microcontroller: AT91SAM7S256C
- ▶ Gyroscope: 2 axis analog output → ADC

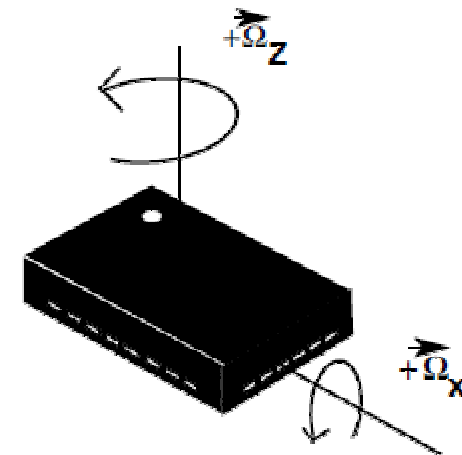
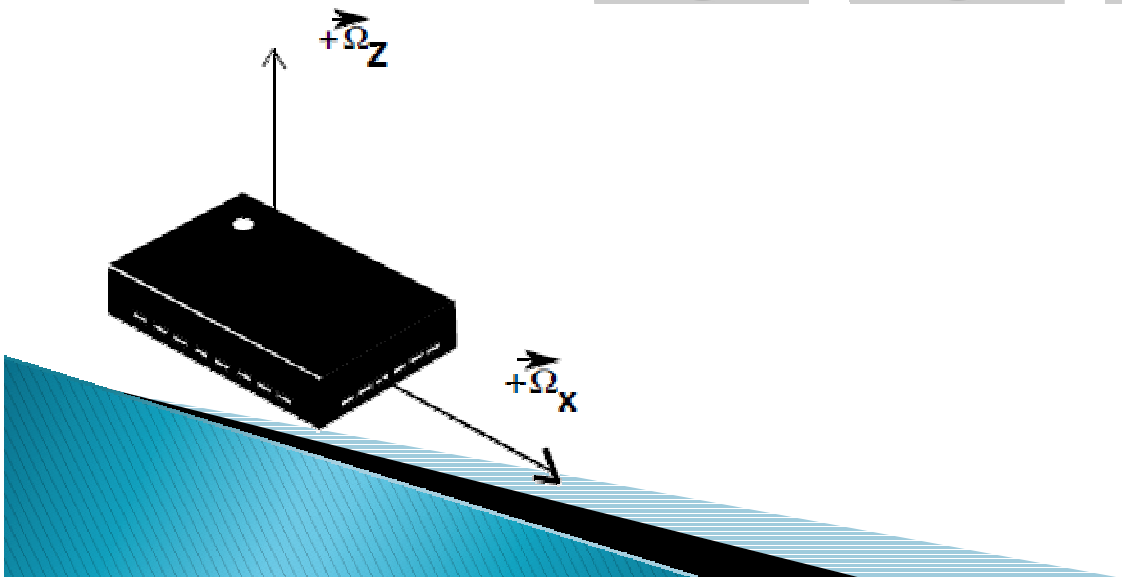
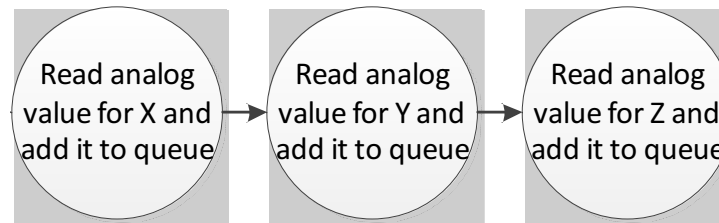


Main FSM



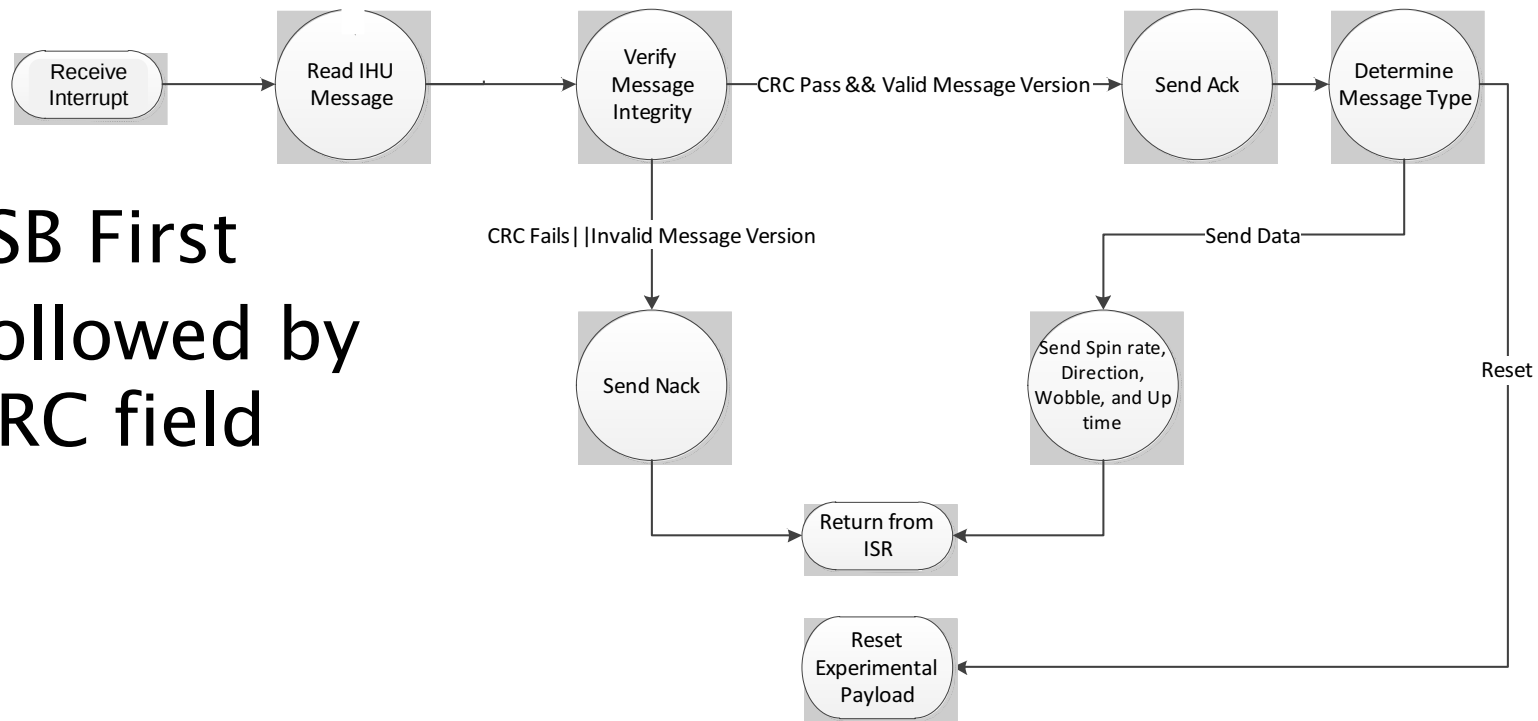
Gyro Subsystem FSM

- ▶ LPY410AL
- ▶ 2 Gyros in different orientations for all 3 axis
- ▶ 10 Hz Sampling rate



Communication ISR FSM

- ▶ LSB First
- ▶ Followed by CRC field



Field	Size (Bytes)	Type	Value	Description
SPIN RATE	2	Signed integer	Variable -50 to +50	Rate of spin of the satellite about the Z axis, in degrees per second. Negative indicates -X spin direction, positive indicates +X spin direction.
DEVIATION	2	Signed integer	Variable -50 to +50	Deviation (wobble) of +Z axis in degrees.
UP TIME	2	Signed integer	Variable 0-32767	Total seconds since experiment payload power-up or reset [FOX1:XSR:3.4.3]~

IHU to Experimental Payload Interface Control Diagram

IHU to Experimental Payload ICD

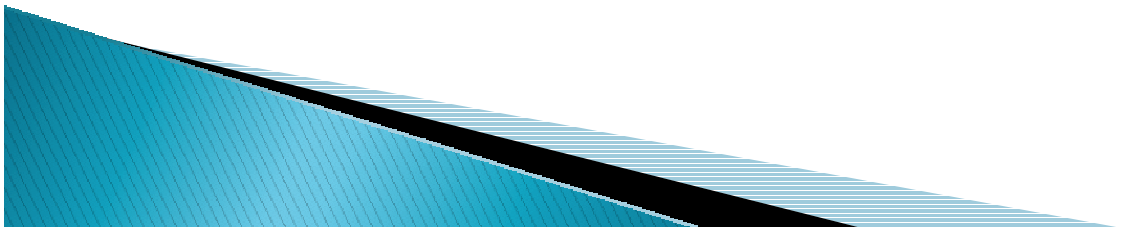
Message Header Block			Message Name Block	Message CRC Block
Start of Message	Message Version	Software Build	Name	CRC
4 Bytes 0xFFFFFFFF	2 Bytes Message ICD Version	2 Bytes Software Build Version	2 Bytes Message name (e.g. 0x0FA0 = "SEND")	2 Byte CRC-16-CCITT

Possible Name Blocks

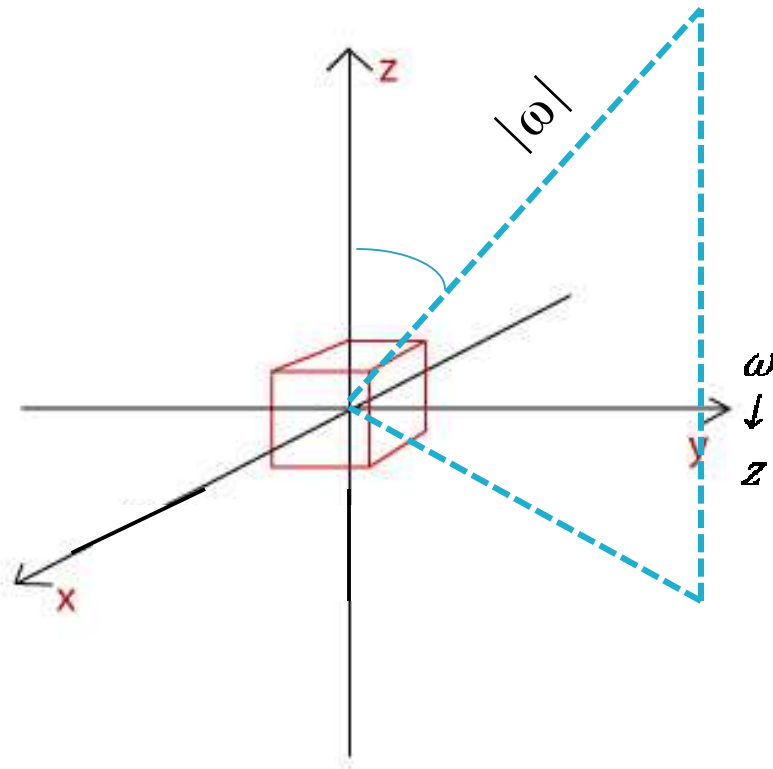
RESET = 0x9F6
SEND = 0xFA0
DATA = 0xBB8
ACK = 0x7D0
NAK = 0x3E8

Response

Data Block		
Spin Rate	Deviation	Up Time
2 Bytes Signed	2 Bytes Unsigned	2 Bytes Unsigned



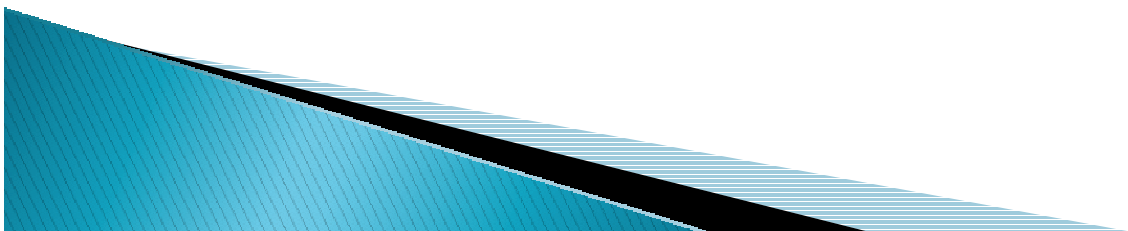
Deviation Algorithm



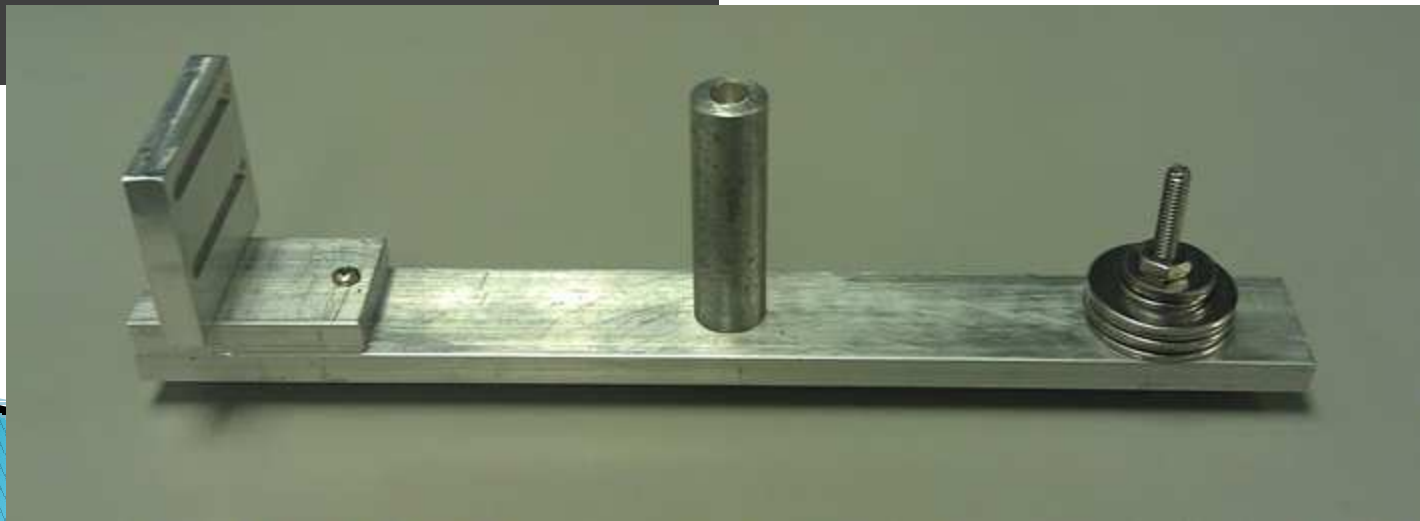
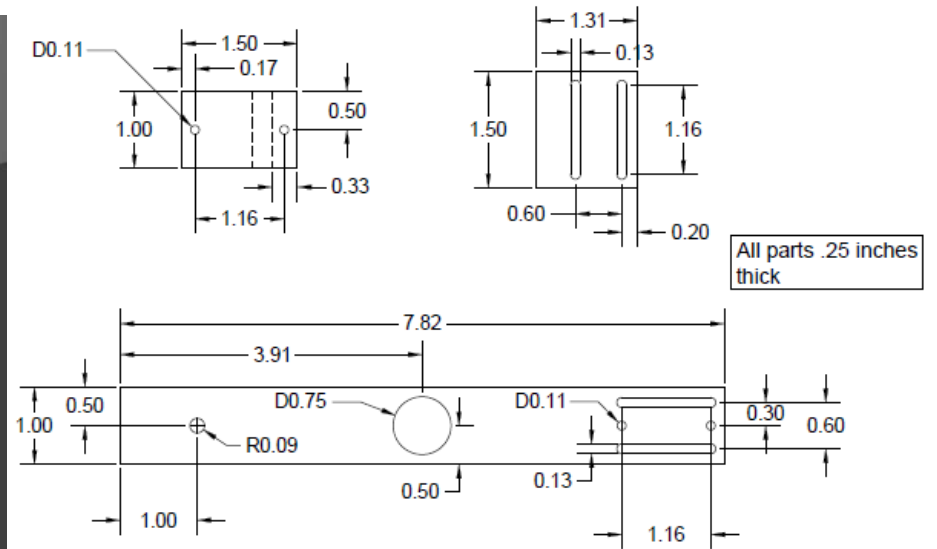
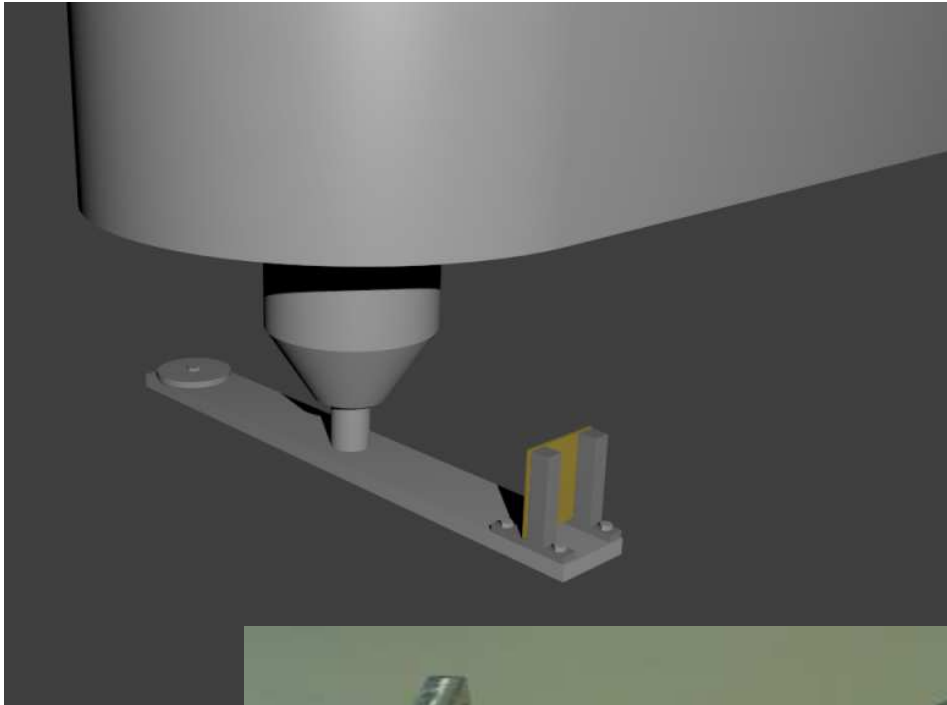
$$\cos \theta = \omega_z / |\omega|$$

$$|\omega| = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2}$$

$$\theta = \cos^{-1} (\omega_z / \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2})$$



Centrifuge Test



Vibrations Test

Test Writer:		Mike Corona					
Test Case Name:		Vibration Unit Test				Test ID#:	Experimental Payload -9.1
Description:		The Experimental Payload must be capable of withstanding the vibration frequencies and amplitudes of launch provided by NASA				Type:	Black Box
Tester Information							
Name of Tester:		Team 1				Date:	
Hardware Ver:		Experimental Payload 1.0				Time:	
Setup:		The Experimental Payload system will be strapped to a shaker.					
Step	Action	Expected Result	Pass	Fail	N/A	Comments	
1	Verify all components of the Experimental Payload system are on and working properly.	All Experimental Payload components are functioning.					
2	Place the Experimental Payload system on the shaker.	The Experimental Payload system will maintain the same position on the shaker.					
3	Set up the shaker to test the board at the vibration and amplitude provided by NASA	The system is programmed and ready to be run.					
4	Turn the shaker on and test the system for 5 minutes.	The Experimental Payload remains in the same position on the shaker.					
5	Power off the shaker after 5 minutes and remove the board.	The Experimental Payload is fully intact (no pieces have fallen off) and in the same condition as started.					
6	Communicate with the Experimental Payload and make sure the gyroscope still functions properly.	The Experimental Payload system still functions properly.					
Overall test result:							

Questions

